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NATIONAL COMMUNICATIONS SYSTEM

TECHNICAL INFORMATION BULLETIN 93-12

**GROUNDING AND BONDING FOR
COMMERCIAL AND GOVERNMENT
BUILDINGS CONFORMING TO
TELECOMMUNICATIONS
INFRASTRUCTURE STANDARDS - A
BACKGROUND REPORT**

JUNE 1993



**OFFICE OF THE MANAGER
NATIONAL COMMUNICATIONS SYSTEM
701 SOUTH COURT HOUSE ROAD
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NCS TECHNICAL INFORMATION BULLETIN 93-12

GROUNDING AND BONDING FOR COMMERCIAL AND GOVERNMENT
BUILDINGS CONFORMING TO TELECOMMUNICATIONS
INFRASTRUCTURE STANDARDS - A BACKGROUND REPORT

JUNE 1993

PROJECT OFFICER



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PUBLICATION:



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Office of Technology
and Standards

FOREWORD

Among the responsibilities assigned to the Office of the Manager, National Communications System, is the management of the Federal Telecommunication Standards Program. Under this program, the NCS, with the assistance of the Federal Telecommunication Standards Committee identifies, develops, and coordinates proposed Federal Standards which either contribute to the interoperability of functionally similar Federal telecommunication systems or to the achievement of a compatible and efficient interface between computer and telecommunication systems. In developing and coordinating these standards, a considerable amount of effort is expended in initiating and pursuing joint standards development efforts with appropriate technical committees of the International Organization for Standardization, and the International Telegraph and Telephone Consultative Committee of the International Telecommunication Union. This Technical Information Bulletin presents an overview of an effort which is contributing to the development of compatible Federal, national, and international standards in the area of Grounding and Bonding for Commercial and Government Buildings. It has been prepared to inform interested Federal activities of the progress of these efforts. Any comments, inputs or statements of requirements which could assist in the advancement of this work are welcome and should be addressed to:

Office of the Manager
National Communications System
Attn: NT
701 S. Court House Road
Arlington, VA 22204-2198

**GROUNDING AND BONDING FOR COMMERCIAL AND GOVERNMENT
BUILDINGS CONFORMING TO TELECOMMUNICATIONS
INFRASTRUCTURE STANDARDS - A BACKGROUND REPORT**

June 1993

**FINAL REPORT
DCA 100-93-M-0027**

**Submitted to:
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CODE NT
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Arlington, VA 22204-2199**

**Submitted by:
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PREFACE

This report is submitted as the final deliverable on Contract DCA 100-93-M-0027. The study was conducted for the Office of the Manager, National Communications System (NCS), Technology and Standards Office, Washington, DC.

This report contains summaries of a series of standards developed by industry under the ANSI process. The series of standards were developed under EIA/TIA until authority was granted to TIA for such standards development. This series is called "Telecommunications Infrastructure" standards in this report. Most of these standards have been, or will, be adopted as mandatory standards within the Federal Government. In particular, this report is meant as an introductory or background report to those users that have not participated in the development of the subject standards and concentrates mainly on the TIA standard (to be published) developed by TIA/TR-41.7.2, Grounding and Bonding in Commercial Buildings (proposed TIA-607).

The author wishes to thank Dr. Dennis Bodson, NCS, for his support of this work and the preparation and mailing of many copies to interested readers. Mr. Robert Adair and Dr. William Kissick, Institute for Telecommunication Sciences (ITS), National Telecommunications and Information Administration, U.S. Department of Commerce, deserve special recognition for their encouragement of this effort, Mr. Jim Romlein, MISLABS, Inc., (Chairman of TR-41.7.2) for his encouragement and review of the report, and Messrs. Michael Meister and Glenn Hanson, ITS for their review and comments on the first seven chapters of the report. Appreciation to all of the many workers who have supported the development of the series of "Infrastructure Standards" and to ECOS Electronics, Inc., for the material summarized in Appendix C. Finally, a word of appreciation to my wife for her patience during the many long hours that have been spent on the development and desktop publishing of this report.

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CHAPTER I TELECOMMUNICATIONS BUILDING INFRASTRUCTURE STANDARDS

1.1 Introduction

Modern telecommunications require an effective telecommunications building infrastructure to support the wide variety of services that rely on the electronic transport of information. The infrastructure is made up of telecommunications equipment spaces, cable pathways, telecommunications wiring and termination hardware, and telecommunications grounding. The infrastructure provides the basic support for the distribution of information within the building. Telecommunications, as used in this report, refers to all forms of information that are conveyed electronically within the building (e.g., voice, data, video, alarms, environmental control, security, audio).

1.2 Background

Early in 1985, a large number of companies representing the telecommunications and computer industry expressed concern over the lack of a standard for telecommunications wiring within commercial buildings. The Computer Communications Industry Association (CCIA) asked the Electronic Industries Association (EIA) to undertake the task of developing such a standard.

EIA standards documents are developed within the Technical Committees of the EIA and the standards coordinating committees of the EIA standards board. Members of the committees serve voluntarily and without compensation. The companies they represent are not necessarily members of EIA. The standards developed within the EIA represent a consensus of the broad expertise on the subject. This expertise comes from within the EIA as well as from those outside the EIA that have an expressed interest. These committees meet under the rules developed by

ANSI to meet "Due Process" that assures all who participate, or subsequently review the document, an opportunity to contribute and to voice objections. The viewpoint expressed at the time a standard is approved is from the contributors' experience and the state of the art at that time. Users of the standards are encouraged to use the latest revision of the standard.

In 1988 the Telecommunications sector of the EIA (specifically the transmission (TR) and fiber optic (FO) Committees and Subcommittees became the TIA (Telecommunications Industry Association) under the TIA Technical Council. In 1992, the TIA was accredited by ANSI as a standards developing organization. Until that time, TIA conducted the standards activities through the EIA organization. Throughout this document, these organizations are referred to as TIA/EIA. Prior to February 1992, the resultant standards, when published, bore the prefix "EIA/TIA." After that date, the prefix is "TIA/EIA."

1.3 Purpose

The purpose of this report is to provide a history of the development and a content summary of the referenced standards for those readers who have not had the benefit of participating in the Working Groups or Sub-working Groups that met regularly to develop the recommended standards.

The report will concentrate particularly on the proposed standard entitled "Commercial Building Grounding and Bonding Requirements for Telecommunications" developed by the ad hoc working group, TIA/EIA TR-41.7.2. The key to the success of the grounding portion of the telecommunications infras-

ture, as addressed in the subject proposed standard, is based on a "ground window" concept. The grounding approach recommended in the subject standard, works conceptually for the wiring topology proposed originally in ANSI/TIA/EIA-568 (telecommunications wiring standard) and installed in accordance with ANSI/TIA/EIA-569 (telecommunications pathways and spaces standard).

1.4 Infrastructure Standards

Paul S. Kreager, a Professional Engineering Consultant and active leader in standards, has described the domestic and international standards activities relating to Telecommunication Infrastructure (Kreager, 1991) as follows:

Infrastructure for telecommunications may be defined as those components of the building that do not change very often; namely, the pathways for media, spaces for equipment, the telecommunication portion of the grounding system and the longer-term portions of the cable plant.

An independent movement to standardize infrastructure components began about 1985 when EIA started development of the Commercial Building Wiring Standard. CSA (Canadian Standards Association) also joined the standards development, resulting in a harmonized North American effort. No similar comprehensive effort is taking place outside North America. However, ISO (ISO, 199X) has recently taken up the task of developing a wiring standard using the EIA wiring standard as a starting point.

Figure I-1 shows the seven-layer Open Systems Interconnection Reference Model (OSI)

which has been adopted by both ISO (IS 7498, 1983) and CCITT Recommendation X.200 (Red Book, 1984). These two standards have been harmonized so that similar wording is obtained throughout the standards.

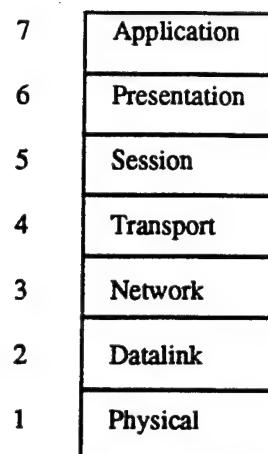


Figure I-1 Seven-Layer OSI Model

The OSI Reference Model partitions the job of transporting information into seven different tasks ranging from providing access to the OSI environment (APPLICATION layer) down to accessing the physical media (wire) itself (PHYSICAL layer). Generally, the higher level functions are implemented in software, while the lower level functions are done in hardware.

The two bottom levels can serve as an example of how the models interact. Level 1 is concerned with getting information onto the medium. It deals with the mechanical, electrical, functional, and procedural aspects of physically getting information onto media like twisted pair, coax, and fiber. Level 1 limits itself to those issues related to getting information into and out of the cable plant, while Level 2 concerns itself with the reliability of moving information to the other end of the link. Therefore, Level 2 adds functionality over Level 1 in order to accomplish

all those tasks inherent in reliable transport of the information to the other end of the data link. In this manner, the levels of the model build on each other with each successively higher level concerned with the next higher level task of moving information through the network.

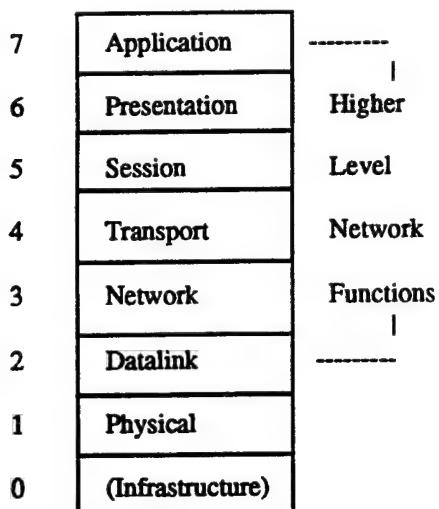


Figure I-2 Modified Seven-Layer OSI Model

The infrastructure components are not covered by the seven-layer ISO model. Yet, when one views the overall job of transporting information, things like conduit, grounding, and closets are exceedingly important. Because of this, a defacto movement among some of the telecommunications professionals has emerged over the last decade or so to define a pseudo Level Zero to include infrastructure components. This is shown in Figure I-2. Level Zero is the place holder for the infrastructure. The idea is that by combining Level Zero with the original seven layers, the end result is a comprehensive definition of all the tasks necessary to transport information.

At the time of this publication, there is only one international standard (ISO, 199X) which corresponds to the North America standards

listed in Table I-1. This standard used the EIA/TIA-568 standard as its initial model but some important differences are evolving between the two. (Many experts estimate at least two years completion time for this standard. The major contributors to the ISO standard are Canada, Denmark, France, Germany, Japan, Sweden, the UK and the US.)

1.5 ANSI/EIA/TIA TR-41 Standards

When EIA accepted the task of developing a standard for telecommunications wiring (as indicated in Section 1.1 above), the project was assigned to TR-41.8 under Engineering Committee TR-41. The TR-41.8 committee was subdivided into three ad hoc working groups as follows:

- (1) TR-41.8.1 - Working Group on Commercial and Industrial Building Wiring Standard
- (2) TR-41.8.2 - Working Group on Residential and Light Commercial Building Wiring Standard
- (3) TR-41.8.3 - Working Group on Building Telecommunications Architecture

The subcommittees of TR-41 as of June, 1993 are as shown in Figure I-3.

1.6 (proposed) EIA/TIA/TR-41.7.2 Standard

During the development of the infrastructure family of building telecommunications standards in the ad hoc working groups of TR-41.8 subcommittee, significant concern was raised, by both Government and industry representatives, about the need for specification of electronic system grounding. This concern resulted in the issuing of TIA-PN-2327 which produced the proposed standard, Table I-1

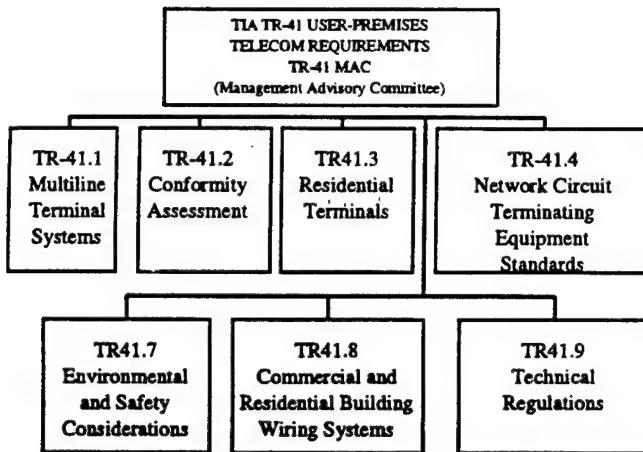


Figure I-3 Organization of TR-41 Subcommittees

(ANSI/TIA/EIA Number 607 to be assigned when approved), entitled "Commercial Building Grounding and Bonding Requirements for Telecommunications".

1.7 EIA/TIA and CSA Standards

Table I-1 lists all the infrastructure-related standards recently introduced or still in development by TIA and CSA in North America. These are listed in approximately the order in which they were first started. This is a family

Table I-1 TIA/EIA and CSA Infrastructure Standards

Infrastructure Component	USA	Canada
Commercial Building Wiring	EIA/TIA-568-1991*	CSA T529*
Residential/Light Commercial Wiring	EIA/TIA-570-1991*	CSA T529* + T530*
Pathways & Spaces	EIA/TIA-569-1990*	CSA T530*
Grounding & Bonding	TIA/EIA-PN-2327	CSA T527
Administration	TIA/EIA-606-1993	CSA T528
Backbone Wiring for Res/Light Commercial	TIA/EIA-PN-2416	CSA T526(Proposed)
Vocabulary	TIA/EIA-PN-2841	

*Available from their respective organizations; others are still in development

of coordinated standards which have been developed, or are in the process of being developed, under the common umbrella of telecommunications as it primarily applies to the modern intelligent building. The standards under development now will require another year for completion.

Upon completion of the work in TR-41.8.3, which was subsequently named Building Pathways and Spaces, this Working Group entered into an effort to develop a proposed new standard entitled "Administration Standard for the Telecommunications Infrastructure of Commercial Buildings" (which has been approved, and published as ANSI/TIA/EIA-606-1993). This proposed draft standard was approved for submission to the TIA for an industry ballot during a meeting held in March 1992. The comments received as a result of this letter ballot were reviewed during the June meeting of this Standards Group. The comments were ruled to be editorial in nature and the subject proposed standard has been approved and has been published as indicated above.

Work on the Commercial Building Grounding and Bonding Requirements for Telecommunications began about the same time as the work on the Administration Standard for the Telecommunications Infrastructure of Commercial Buildings. A final draft was approved for submission to TIA for ballot comments by the TR-41.7 subcommittee membership at the June meeting. These ballot comments were reviewed at the September 1992 meeting. The proposed standard was sent out for Industry Ballot as SP-2327 following the September meeting. Discussion of the comments from this ballot was carried out at the March 1993 meeting. Further discussion of each of these standards will be pursued in Chapter II of this report.

The Backbone Wiring standard (PN-2416) applies to the Residential/Light Commercial Wiring standard. It is in progress under TR-41.8.4, as of the writing of this report. This standard will not be considered in this report.

Finally, a new standards activity (PN 2841) under TR-41.8.5 will harmonize the terms and definitions in each of these standards to assure that a term appearing in one standard in this family of infrastructure standards will mean the same in another standard. There is no intent for this work to become a stand-alone standard. It will not be considered in this report.

1.8 Federal Standards

In addition to the standards described above and those in progress under the auspices of TIA/EIA TR-41, it should be noted that each of the Building Infrastructure Standards is being adopted as a Federal Information Processing Standard (FIPS). The corresponding numbers are shown in Table I-2. (The numbers for proposed Federal Standards reflect earlier plans, now changed. The industry standards have been, or will be, adopted as FIPS Publications.)

TIA/EIA Standard	Federal Standard	FIPS PUB
EIA/TIA-568-1991	pFS 1090	174
EIA/TIA-569-1990	pFS 1091	175
EIA/TIA-570-1991	pFS 1092	176
TIA/EIA-PN-2290 Proposed TIA/EIA-606	pFS 1093	
TIA/EIA-PN-2416		
TIA/EIA-PN-2841		

Table I-2 Building Infrastructure Standards

1.9 Technical Background Report (PN-2771)

PN-2771 was approved by TIA for the preparation of a technical background report on

the Grounding and Bonding Requirements for Telecommunications in Commercial Buildings (PN-2327, to be published as ANSI/TIA/EIA-607-199x). This report, to be submitted to the National Communications System (sponsor) for consideration as a Technical Information Bulletin (TIB), constitutes the response to that Project Number.

REFERENCES

Kreager, Paul S. (1991), Standards, Cabling Business Magazine, P.O. Box 476177, Garland, TX 75047-6177, November/December

ISO (199X), Customer Premises Cabling Standard (does not have a number), ISO/IEC/JTC1/SC25/WG3, (when available, ANSI, 1430 Broadway, New York, NY 10018)

Red Book (1984), CCITT Recommendation X.200, Reference Model of Open Systems Interconnection for CCITT Applications, International Telecommunications Union, Place des Nations, CH 1211, Geneva 20, Switzerland

ISO-IS 7498 (1984), Open Systems Interconnection - Basic Reference Model, ANSI, ISO TC 97/SC 6 Secretariat, 1430 Broadway, New York, NY 10018

CHAPTER II ANSI/EIA/TIA STANDARDS

2.1 Introduction

The family of telecommunication standards (infrastructure standards) described in the previous part of this report, namely ANSI/EIA/TIA (-568, -569, -570 and -606) recognize a basic precept of fundamental importance: to have a building successfully designed, constructed, and provisioned for telecommunications, it is imperative that the telecommunications design be incorporated during the preliminary architectural design. These buildings are often planned and constructed without prior knowledge of the telecommunications equipment and systems that will subsequently be installed in them and the telecommunications grounding and bonding system infrastructure is frequently designed and installed long before the needs of the tenant are known. Despite these unknowns, the building grounding and bonding infrastructure must be applicable to all telecommunications equipment. It must not be specific to a particular equipment or system, but must be capable of supporting a multivendor, multiproduct environment.

2.2 ANSI/EIA/TIA-568-1991, *Commercial Building Telecommunications Wiring Standard* (Currently being revised)

This standard specifies minimum requirements for telecommunications wiring within a building and between buildings in a campus environment. It specifies a wiring system with a recommended topology and recommended distances. It specifies copper and optical-fiber transmission media by parameters that determine performance, and specifies connectors and their pin assignments to ensure interconnectability.

The purpose of this standard is to facilitate transportability among telecommunication facilities and systems and compatibility of

these facilities and systems at the computer-communications interface with data processing equipment (systems) by specifying standard characteristics for building telecommunications wiring. This standard defines a generic, functional telecommunications wiring system for commercial buildings that will support a multiproduct, multivendor environment. The further purpose of this standard is to enable the planning and installation of building wiring with little knowledge of the telecommunications products that subsequently will be installed. Installation of wiring systems during building construction or major renovation is significantly less expensive and less disruptive than after the building is occupied. This standard establishes performance and technical criteria for a recommended wiring topology. To attain a building that will support a multivendor, multiproduct environment, a review of the performance requirements for most telecommunications services was conducted during preparation of the ANSI/EIA/TIA standard. The diversity of telecommunications services currently available, coupled with the continual addition of new services, means that there may be cases where limitations to desired performance occur. To understand any such limitations, the user is advised to consult standards associated with the desired services.

Adherence to a standard that specifies standardized building wiring contributes to the economic and efficient use of resources by avoiding proliferation of local or vendor-unique standards, and is necessary to facilitate development of transportable inter- and intrabuilding telecommunications systems. Specification of minimum acceptable values for basic performance parameters provides assistance to the user in multivendor procurement. For the user requiring state-of-the-

art systems performance, these values may serve as benchmarks for use in cost/performance analyses when evaluating alternate transmission media whose specifications exceed those of this standard.

Since this standard is being widely recognized and used, not only in North America but in many other parts of the world (Gearing, 1991), it seems appropriate to expand the summary presented here. The physical topology recommended in this standard is a hierarchical star. This supports both centralized and distributed architecture systems and provides central points for management and maintenance. The topology recommended in the standard is shown in Figure II-1. This star topology can be configured to support ring, bus and tree applications.

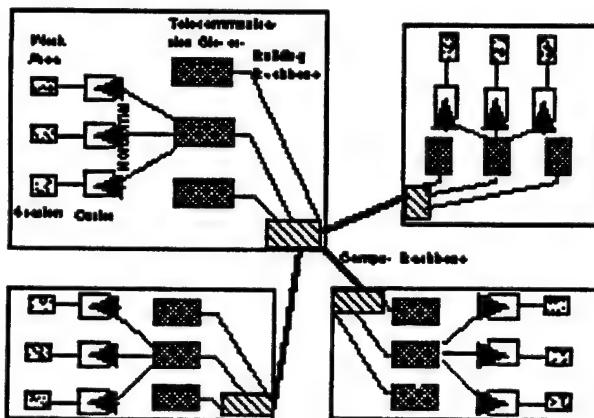


Figure II-1 Wiring Topology for EIA/TIA-568-1991

The wiring system consists of passive components and is broken out into three main elements:

- (1) *Work Area* the connection between the station and the outlet
- (2) *Horizontal* the connection between, and including, the outlet and the termination in the telecommunication closet

(3) *Backbone* the connection between the telecommunication closet and equipment room(s) within a building and the connection between buildings

The horizontal is limited to 90 meters between the telecommunication closet and the station outlet. This is independent of the media type so that the telecommunication closet is common to all media and all applications operating over the media. There is an allowance for 3 meters in the work area and 6 meters, for patching, in the closet, totaling 99 meters. The recommended media and connectors for the horizontal are:

- o 100-ohm unshielded twisted pair - 4 pairs, 8-pin modular connector (ISDN)
- o 150-ohm shielded twisted pair - 2 pairs, IBM connector
- o 50-ohm coax (thin) - IEEE 10BASE2, standard BNC connector
- o 62.5/125-micrometer multi mode fiber - no connector selected

As the standard is revised, new media with increased performance will be recommended. Therefore, each of the infrastructure standards strongly recommend that the latest version of the standard be used.

In the backbone a maximum of two levels of crossconnect is recommended. The recommended media for the backbone are:

- o 100-ohm unshielded twisted pair - multi-pair
- o 150-ohm shielded twisted pair - 2 pair

- o 50-ohm coax (thick) - IEEE 10BASE5
- o 62.5/125-micrometer multi-mode fiber

The maximum distances recommended for the different media in the backbone are shown in Figure II-2.

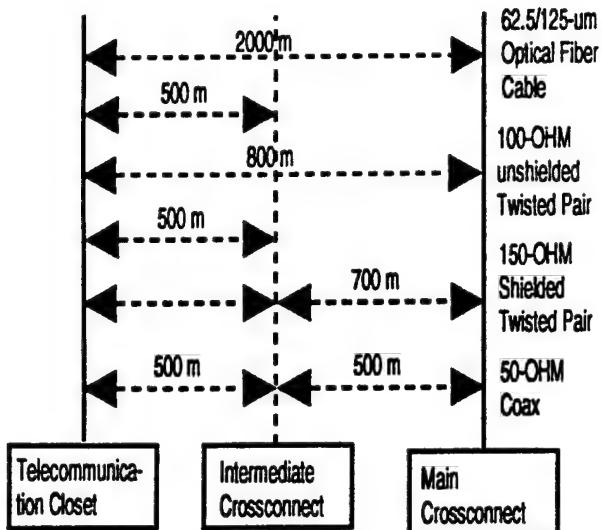


Figure II-2 Maximum Distances Specified for Backbone in 568 Standard

2.3 ANSI/EIA/TIA-569-1990, *Commercial Building Standard for Telecommunications Pathways and Spaces* (Currently being revised)

The purpose of this standard is to specify design and construction practices for telecommunications pathways and spaces, which are in support of telecommunications media and equipment, within and between commercial buildings. Specifications are given for rooms, areas, and pathways into and through which telecommunications equipment and media are to be installed. A conceptual layout of a building showing the telecommunications pathways and spaces defined in this standard is shown in Figure II-3.

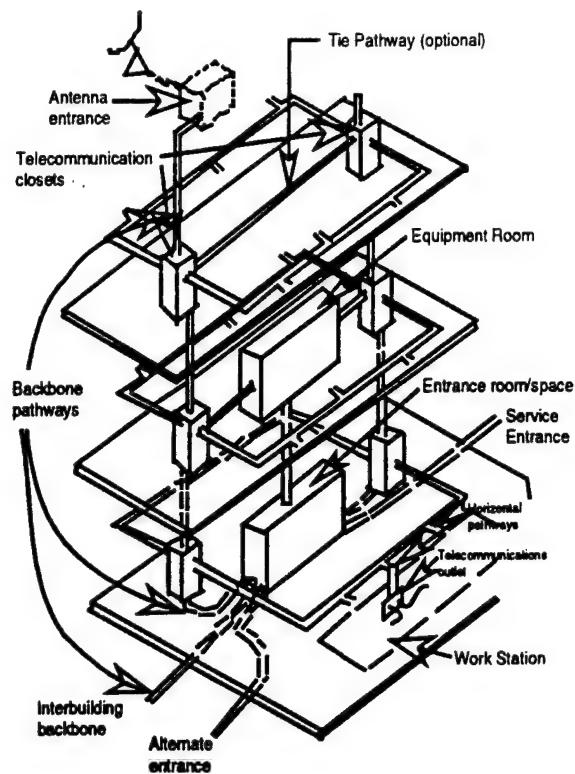


Figure II-3 Conceptual Layout of Building Elements [after EIA/TIA-569-1990]

This standard is the result of a joint Canadian and United States effort by the Canadian Standards Association (CSA) and the Telecommunications Industry Association (TIA). In August of 1987, CSA and EIA decided to combine the efforts of the Canadian T530 committee, which had been independently pursuing similar standards goals, and the United States TR-41.8.3 Working Group. The resulting standard is published separately in each country, the core sections of both being very similar, with only minor differences to accommodate such things as language variations, national electrical codes, style, and format.

The standard recognizes that building wiring cannot be standardized without also standardizing the architecture of the building itself into which building wiring systems are in-

stalled. Consequently, a strong attempt was made to coordinate the activities of the TIA TR-41.8 and the CSA T530 standards efforts. In the United States, development of the standard was carried out with the support of the American Institute of Architects and the Construction Specifications Institute. Because the standard highly influences both the design and construction of commercial buildings, it was important that these two organizations be cognizant of this particular standards activity. Additionally, the prospect of the architectural and construction industries being confronted with a national standard related to access to telecommunications services made it necessary that they be given a clear rationale for the need of such a standard.

2.4 ANSI/EIA/TIA-570-1991, *Residential and Light Commercial Telecommunications Wiring Standard*

The purpose of this standard is to facilitate interoperability and transportability among telecommunication facilities and systems and compatibility of these facilities and systems at the computer-communications interface with data processing equipment (systems) by specifying standard characteristics for telecommunications wiring for *small buildings*.

It gives an overview of premises wiring, and specifies installation requirements and component technical requirements. Appendices provide information on line assignments in selected network interface jacks, wiring installation guidelines, component description, and references to related standards and other documents.

This standard describes a premises-wiring system intended for connecting one to four exchange access lines to various types of customer-premises equipment. It defines a generic, functional telecommunications wiring system intended for connecting one to

four exchange access lines to various types of customer-premises equipment. This creates a generic, functional telecommunications wiring system that will support a multiproduct, multivendor environment.

2.5 ANSI/EIA/TIA-606-1993, *Administration Standard for the Telecommunications Infrastructure of Commercial Buildings*

Administration of telecommunications includes documentation (recordkeeping, drawings, labeling, etc.) of telecommunications outlet boxes and connectors, cables, termination hardware, patching and crossconnect facilities, conduits, other cable pathways, telecommunications closets, and other spaces. The complex telecommunications building infrastructure addressed by this ANSI/EIA/TIA family of standards requires continuing documentation of all building wiring and related pathways and spaces that contain that wiring. Recognizing the need for a standardized method of telecommunications administration, TIA has developed ANSI/TIA/EIA-606-1993, *Administration Standard for the Telecommunications Infrastructure of Commercial Buildings*, to expedite the collecting and updating of such information.

2.6 ANSI/EIA/TIA-607-199X, *Commercial Building Grounding and Bonding Requirements for Telecommunications*

During the development of this family of building telecommunications standards, significant concern was expressed, by both Government and industry, about the need for specification of electronic system grounding. This concern resulted in proposed ANSI/TIA/EIA-607, *(Commercial Building Grounding and Bonding Requirements for Telecommunications)*. The following technical report will provide an expanded description of some of the elements and some additional background material.

Grounding within buildings accomplishes multiple functions, all of which must be considered in the design and installation of sensitive electronic equipment. Grounding is required both for safety reasons and because of the need for highly sensitive electronic systems (SES) to operate reliably. Safety takes top priority, but SES grounding must be simultaneously safe and operationally reliable. The purpose of grounding for SES is to assure that all interconnected and grounded conductors are at the same potential in a given sensitive electronic system environment. It is not necessary that this uniform potential, say for a given system in a high-rise building, be the same as the earth potential at a given instance.

2.7 Outline of This Technical Report

Chapter III discusses the sections of the proposed grounding standard. Chapter IV presents some background material describing the goals of grounding of sensitive electronic systems (SES) in buildings. Chapter V presents some principles and theory of grounding and bonding that may help in understanding the proposed standard. Chapter VI presents a "Ground Window" concept that specifically applies to the architecture and requirements of the ANSI/EIA/TIA/CSA series of standards. Chapter VII will define exposure of telecommunications sites. Appendix A presents a Bibliography of Handbooks, Technical Papers, and Public Domain Practices that should be helpful to achieve a more thorough understanding of the materials presented in this report and the proposed ANSI/TIA/EIA-607 standard. Appendix B contains a paper, that was presented at SuperCom '90 held in Atlanta, Georgia. It describes the several subsystems required for grounding of Commercial or Government buildings. Appendix C is an edited version of a document, that was submitted to the TIA/TR41-7.2 Working Group, which pro-

vides guidance for power system installations needed for some large SES installations.

REFERENCES

ANSI/EIA/TIA-568 (1991), Commercial Building Telecommunications Wiring Standard, EIA/TIA Engineering Department, 2001 Pennsylvania Avenue, N.W., Washington, D.C. 20006, July

Gearing, Bryan F. (1991), Building Wiring Standards and their impact on LANs, Proceedings of the High-Speed Networks and Channels, SPIE Vol. 1577

ANSI/EIA/TIA-569 (1990), Commercial Building Standard for Telecommunications Pathways and Spaces, EIA/TIA Engineering Department, 2001 Pennsylvania Avenue, N.W., Washington, D.C. 20006, October

ANSI/EIA/TIA-570 (1991), Residential and Light Commercial Telecommunications Wiring Standard, EIA/TIA Engineering Department, 2001 Pennsylvania Avenue, N.W., Washington, D.C. 20006, June

CHAPTER III PN-2327-COMMERCIAL BUILDING GROUNDING AND BONDING REQUIREMENTS FOR TELECOMMUNICATIONS

3.1 Introduction

Grounding and bonding is an important consideration for the safe and reliable operation of telecommunications equipment and systems found in many of today's commercial buildings. (The complex nature of the grounding systems in these buildings is shown in Figure III-1. The Telecom grounding subsystem is emphasized here.) These buildings are often planned and constructed without prior knowledge of the telecommunications equipment and systems that will subsequently be installed in them and the telecommunications grounding and bonding system infrastructure is frequently designed and installed long before the needs of the tenant are known. Despite these unknowns, the building grounding and bonding infrastructure must be applicable to all telecommunications equipment. It must not be specific to a particular equipment or system, but must be capable of supporting a multivendor, multiproduct environment.

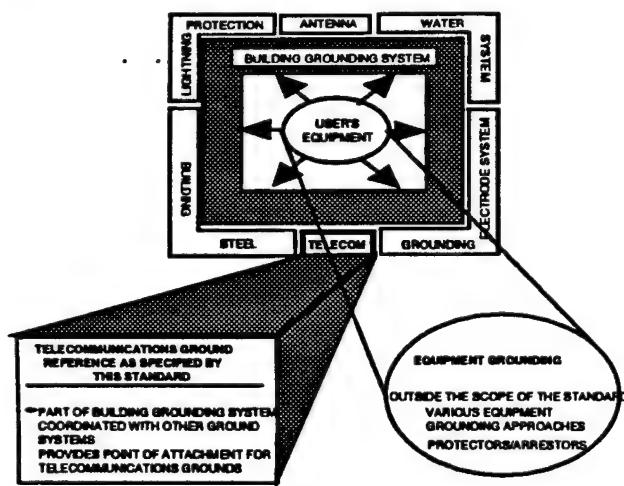


Figure III-1 Building Grounding System

(Bonding, as defined in this report and in the proposed standard, is the "permanent joining

of metallic parts to form an electrically conductive path which will assure electrical continuity and the capacity to conduct safely any current likely to be imposed.")

This emphasis makes it necessary to seek a generalized solution to bonding and grounding rather than the adoption of proprietary practices designed for specific commercial equipment installations.

The grounding and bonding approach described in this report works in concert with the wiring topology as specified in ANSI/EIA/TIA-568-1991 (ANSI/EIA/TIA-568, 1991) and installed in accordance with ANSI/EIA/TIA-569-1990 (ANSI/EIA/TIA-569, 1990). (These standards were summarized in Chapter II of this report.) References to other related standards and practices may be found in the Bibliography presented in APPENDIX A of this report.

The National Electrical Code (NEC) (NFPA-70, 1990) provides guidelines to ensure that electrical installations in buildings meet the necessary safety practices to prevent electrical shock hazards to personnel and to ensure fault clearance of unintentional electrical breakdowns that could cause fires. This code does not imply that adequate grounding will be provided to ensure:

- (1) continued performance of electronic equipments and systems without mutual interference; or
- (2) that a quiet ground structure will be provided to allow equipments to be isolated from external interference, either

conducted or radiated. (Note: This quiet ground structure is equivalent to the sensitive electronic systems (SES) ground described in this report.)

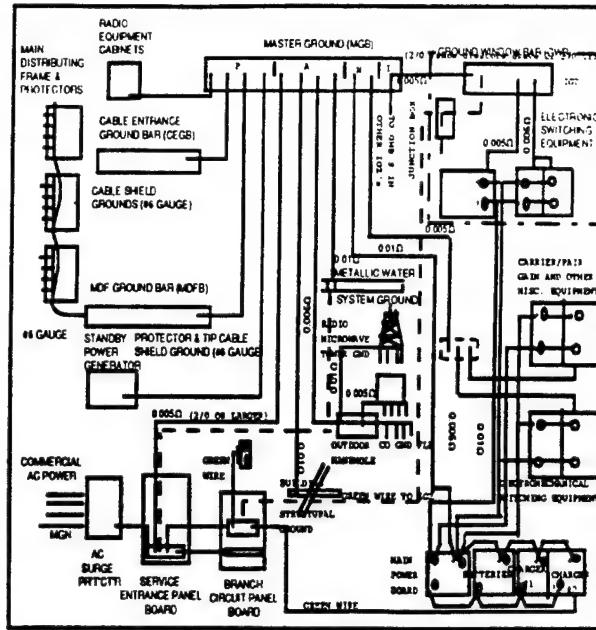
The NEC requirements must be met as well as any other local codes that are required. The subject standard addresses the issues of (1) and (2) above. A code, as generally defined, is a system of principles or rules given statutory force (Minichiello, 1992)

The requirements specified in this performance standard in conjunction with a basic understanding of the grounding concepts presented within, will aid the user in achieving a reliable grounding solution when applied to specific telecommunications grounding requirements.

3.2 Background

A large resource of information exists within the telephone industry in the form of telephone utility company practices and guidelines (e.g., See Appendix A, Doc. Reg.) However, there are presently no U.S. standards that address telecommunications grounding and bonding in commercial buildings from a functional perspective.

Initially, the TIA Working Group considered several standards or practices that were brought to the attention of the group by various sources. One of those that received attention was a nonproprietary document (REA, 1983) which contained a diagram similar to that shown in Figure III-2. This (simplified) drawing indicates the main elements of the grounding systems when applied to a central office switch building. Another nonproprietary document (ANSI T1.313, 1991) contains a diagram of a base standard for the Electrical Protection For Telecommunications Central Offices and Similar Type Facilities.



The standard (after extensive review and modifications) specifies a "Telecom" grounding architecture which, in conjunction with other grounding and bonding systems, makes up the telecom grounding portion of the overall building grounding system as depicted in Figure III-1. The standard specifies the requirements for providing:

- 1) a ground reference for telecommunications systems within the telecommunications entrance facility;
- 2) a ground reference for telecommunications systems within the telecommunications closet and equipment room;
- 3) integration of power and telecommunications grounding systems; and
- 4) the bonding and associated connection requirements for pathways, cable sheaths, conductors, and hardware at telecommunications closets, equipment rooms and entrance facilities.

A final conceptual layout of the grounding system, along with the building spaces defined in EIA/TIA-569-1990, is shown in Figure III-4 [ca June 1993]. The building spaces include the entrance facility, the equipment room, the telecommunications closet, the electrical closets, and the work area. These will be discussed in more detail later in this report.

3.3 Definitions

Each of the standards in this family presents a set of terms relevant to the specific standard. During the development of EIA/TIA-569-1990, a vocabulary group (led by David Juden, CSA and Glenn Hanson, EIA/TIA) came up with an extensive list of terms and definitions. After that standard was

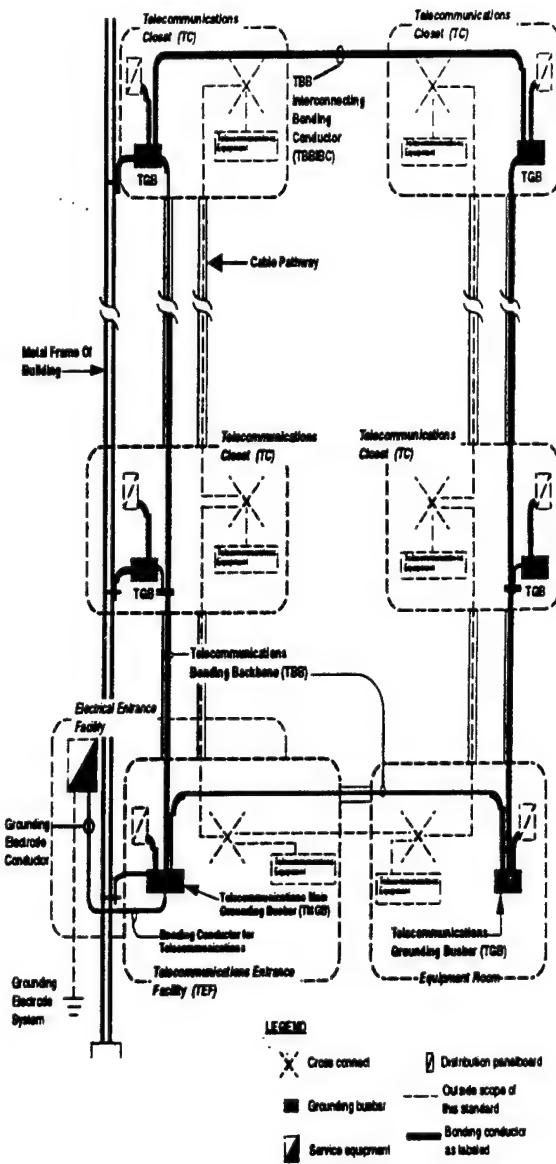


Figure III-4 Scope of the Standard for Large Commercial Buildings

developed, a search was made of all the terms used in the standard and the remainder of the list, developed by the vocabulary group, was removed from the standard.

For an extensive list of terms and definitions, the reader is referred to the IEEE Standard Dictionary of Electrical and Electronics Terms (IEEE Dictionary, 1984) or Federal Standard 1037B, Telecommunications:

Glossary of Telecommunication Terms (FS-1037B, 1991). A new Working Group, TR-41.8.5 Common Definitions Group was formed at the June 1992 meeting of TR-41.8 to review all of the terms and definitions found in the infrastructure standards and harmonize these definitions so that a given word will reflect the same meaning regardless of where it is used in this series.

3.4 Overview of the Telecommunications Grounding and Bonding Infrastructure

The four major elements of the Figure III-4 Scope of Current Standard telecommunication grounding system, defined by this standard, are the:

- 1) Grounding Electrode System,
- 2) Telecommunications Main Grounding Busbar (TMGB)
- 3) Telecommunications Bonding Backbone (TBB), and
- 4) Telecommunications Grounding Busbar (TGB).

These elements in conjunction with the building spaces and pathways, comprise the telecommunications grounding and bonding infrastructure. These building spaces and pathways are the:

- 1) Telecommunications Entrance Facility (TEF),
- 2) Telecommunications Closet (TC),
- 3) Electrical Closet, and
- 4) Interconnecting Pathways.

The above elements are described in much more detail in Chapter IV of this report (Grounding Systems Overview). Safety is taken as the most important concern in grounding. Thus, it is extremely important to consider the relation of the telecommunication grounding system and the power grounding. This will be dealt with in much greater detail in APPENDIX C of this report.

Because of the topology of the telecommunication wiring system adopted in EIA/TIA-568-1991 and expanded upon in EIA/TIA-569-1990, (summarized in Chapter II of this report) all work areas, connected through a telecommunications closet, may be fed through a "ground window" as described in Chapter VI of this report.

3.4.1 Grounding Electrode System

The grounding electrode system is defined in the National Electrical Code (NFPA-70, 1990) in sections 250-81 and 250-83:

If available on the premises at each building or structure served, each item (a) through (d) below, and any made electrodes in accordance with Section 250-83(c) and (d), shall be bonded together to form the grounding electrode system.

(a) Metal Underground Water Pipe. A metal underground water pipe in direct contact with the earth for 10 feet (3.05 m) or more (including any metal well casing effectively bonded to the pipe) and electrically continuous (or made electrically continuous by bonding around insulating joints or sections of insulating pipe) to the points of connection of the grounding electrode conductor and the bonding conductors. Continuity of the grounding path or the bonding connection to interior piping shall not rely on water meters. A metal underground water pipe shall be supplemented by an additional electrode of a type specified in Section 250-81 or in Section 250-83. The supplemental electrode shall be permitted to be bonded to the

grounding electrode conductor, the grounded service-entrance conductor, the grounded service raceway, any grounded service enclosure, or the interior metal water piping at any convenient point.

Where the supplemental electrode is a made electrode as in Section 250-83(c) or (d), that portion of the bonding jumper which is the sole connection to the supplemental grounding electrode shall not be required to be larger than No. 6 copper wire or No. 4 aluminum wire.

(b) Metal Frame of the Building. The metal frame of the building, where effectively grounded.

(FPN): Effectively grounded means intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages which may result in undue hazard to connected equipment or to persons.

(c) Concrete-Encased Electrode. An electrode encased by at least 2 inches (50.8 mm) of concrete, located within and near the bottom of a concrete foundation or footing that is in direct contact with the earth, consisting of at least 20 feet (6.1 m) of one or more steel reinforcing bars or rods of not less than 1/2 inch (12.7 mm) diameter, or consisting of at least 20 feet (6.1 m) of bare copper conductor not smaller than No. 4 AWG.

(d) Grounding Ring. A ground ring encircling the building or structure, in

direct contact with the earth at a depth below earth surface not less than 2 1/2 feet (762 mm), consisting of at least 20 feet (6.1 m) of bare copper conductor not smaller than No. 2 AWG.

250-83. Made and Other Electrodes. Where none of the electrodes specified in Section 250-81 is available, one or more of the electrodes specified in (b) through (d) below shall be used. Where practicable, made electrodes shall be embedded below permanent moisture level. Made electrodes shall be free from nonconductive coatings, such as paint or enamel. Where more than one electrode is used, each electrode of one grounding system (including that used for lightning rods) shall not be less than 6 feet (1.83 m) from any other electrode of another grounding system.

(FPN): Two or more electrodes that are effectively bonded together are to be treated as a single electrode system in this sense.

(a) Metal Underground Gas Piping System. A metal underground gas piping system shall not be used as a grounding electrode.

(b) Other Local Metal Underground Systems or Structures. Other local metal underground systems or structures, such as piping systems and underground tanks.

(c) Rod and Pipe Electrodes. Rod and pipe electrodes shall not be less than 8 feet (2.44 m) in length and shall consist of the following

materials, and shall be installed in the following manner:

(1) Electrodes of pipe or conduit shall not be smaller than 3/4-inch trade size and, where of iron or steel, shall have the outer surface galvanized or otherwise metal-coated for corrosion protection.

(2) Electrodes of rods of iron or steel shall be at least 5/8 inch (15.87 mm) in diameter. Nonferrous or stainless steel rods or their equivalent less than 5/8 inch (15.87 mm) in diameter shall be listed and shall not be less than 1/2 inch (12.7 mm) in diameter.

(3) The electrode shall be installed such that at least 8 feet (2.44 m) of length is in contact with the soil. It shall be driven to a depth of not less than 8 feet (2.44 m) except that where rock bottom is encountered, the electrode shall be driven at an oblique angle not to exceed 45 degrees from the vertical or shall be buried in a trench that is at least 2 1/2 feet (762 mm) deep. The upper end of the electrode shall be flush with or below ground level unless the aboveground end and the grounding electrode conductor attachment are protected against physical damage as specified in Section 250-117.

(d) **Plate Electrodes.** Each plate electrode shall expose not less than 2 square feet (0.186 sq m) of surface to exterior soil. Electrodes of iron or steel plates shall be at least 1/4 inch (6.35 mm) in thickness. Electrodes of nonferrous metal shall be at least 0.06 inch (1.52 mm) in thickness.

(e) **Aluminum Electrodes.** Aluminum electrodes shall not be permitted.

3.4.1.1 Connectivity to the Grounding Electrode System

The purpose of this section in PN-2327 is to set forth the guidelines in establishing the attachment of the telecommunications infrastructure to the grounding electrode system. It is anticipated that establishing a common point or bus will serve as a common, accessible, and controlled access to the facilities' electrode system for telecommunications ground referencing. The electrical service entrance must also be bonded to this same point in order to assure safety of the system. This will be done in accordance with the applicable codes. The connectivity to the grounding electrode system is shown schematically in Figure III-5. [Note: this is also the Scope of the Standard for Smaller Commercial Buildings.] The physical interface to the grounding electrode system is via the telecommunications main ground busbar (TMGB) in this Figure. Grounding and bonding of other systems than the telecommunications systems (e.g., metallic components entering the building, and metallic components external to the building) must be in accordance with applicable codes.

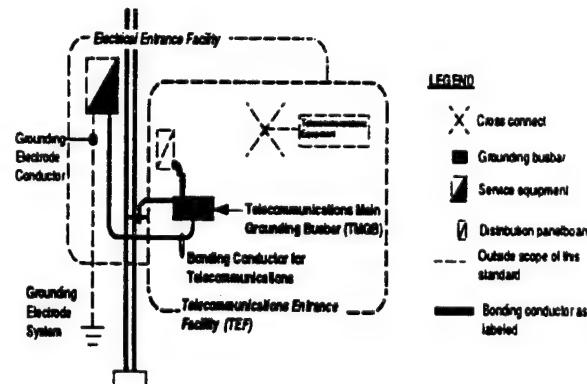


Figure III-5 Connectivity to the Grounding Electrode System

3.4.2 Telecommunications Main Grounding Busbar (TMGB)

The TMGB is intended to serve as the interface between the grounding electrode system (described above) and the Telecommunications Bonding Backbone (TBB). The location of the TMGB should be in the entrance room or space in order to minimize the length of the bonding conductor to the grounding electrode system. This common point will serve as a common, accessible, and controlled access to the facilities' electrode system for telecommunications ground referencing. The telecommunications entrance facility (TEF) includes the room or space within the building where telecommunications services enter, where the joining of inter- and intra-building backbone facilities takes place, and where the proper grounding and bonding of these facilities is accomplished. The TEF may also contain antenna entrances and electronic equipment serving telecommunications functions. The electrical service entrance must also be bonded to this same point in order to assure safety of the system. This will be done in accordance with the applicable codes. The extension busbars of this TMGB are located in the Telecommunications Closets and are known as Telecommunications Grounding Busbars (TGB). The telecommunications closet on each floor is a transition point between the backbone and horizontal pathways and will contain telecommunications equipment, cable terminations and associated crossconnect wiring. A full specification detailing sizes, constraints, pathways, and spaces for the telecommunications closet is contained in the ANSI/EIA/TIA-569-1990 standard (ANSI/EIA/TIA-569, 1990).

The current draft of PN 2327 provides detailed descriptions, and recommended dimensions, of the typical TMGB.

3.4.3 Telecommunications Bonding Backbone (TBB)

The telecommunications bonding backbone (TBB) interconnects telecommunications closets located in the backbone pathway of the telecommunications system. The TBB originates at the entrance facility, extends throughout the building using the telecommunications pathways and is accessible at all telecommunications closets. The TBB is made accessible via a TGB at each telecommunications closet and equipment room. The TBB's function is to reduce or equalize potential differences between telecommunications systems attached to it. A TBB is not intended to serve as the conductor providing a ground fault current return path, required for actuating ground fault overcurrent protection devices.

In metal frame buildings that are effectively grounded, each TBB shall be bonded to the metal frame at each floor using a bonding conductor as sized in accordance with the standard. The building metal column selected for bonding to the TBB should not be the same one selected as the down-conductor for the lightning protection system.

3.4.4 Telecommunications Grounding Busbar (TGB)

The Telecommunications Grounding Busbar (TGB) is the common point of connection for telecommunications systems and equipment to the telecommunications grounding and bonding infrastructure. This ground reference should be relatively free of the stray ground currents that are often found on other shared building grounding systems.

The bonding conductor between the TBB and TGB must be continuous and without splice or joint and routed in a short straight-line path, where possible.

3.5 Telecommunications Entrance Facility

The telecommunications entrance facility (TEF) includes the room or space within the building where telecommunications services enter, where the joining of inter- and intra-building backbone facilities takes place, and where the proper grounding and bonding of these facilities is accomplished. The TEF may also contain antenna entrances, and electronic equipment serving telecommunications functions. The TEF is the desirable location for the TMGB. This TMGB may serve as the TGB for collocated equipment as appropriate. The TMGB is the common point in the TEF to which all grounding connections for the room are made.

When an ac panelboard is located within the TEF and it serves telecommunications equipment within the TEF, the TGB serving that equipment should be located within 2 m of this panelboard and shall be installed as per applicable electrical codes.

When grounding bars are incorporated in pieces of equipment located in the TEF, (e.g., fiber optic termination equipment) they shall be bonded to the TMGB.

3.6 Telecommunications Closet

The telecommunications closet on each floor is a transition point between the backbone and horizontal pathways and will contain telecommunications equipment, cable terminations and associated cross-connection wiring. A full specification detailing sizes constraints, pathways, and spaces for the telecommunications closet is contained in the ANSI/EIA/TIA-569-1990 Standard (ANSI/EIA/TIA-569, 1990).

3.7 Electrical Closet

The electrical power panels and transformers contained in the electrical closet should serve the same work areas. This will make the

grounding window concept developed in Chapter VI of this report valid.

3.8 Testing and Maintenance

Although testing and maintenance is not covered in the standard, there is considerable evidence that many problems may result when no testing and maintenance are done on such an installation.

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CHAPTER IV GROUNDING SYSTEMS OVERVIEW

4.1 Introduction

Grounding within buildings accomplishes multiple functions, all of which must be considered in the design and installation of sensitive electronic equipment. Grounding is required both for safety reasons and because of the need for highly sensitive electronic systems (SES) to operate reliably. Safety takes top priority, but SES must be simultaneously safe and operationally reliable. The purpose of grounding for SES is to assure that all interconnected and grounded conductors are at the same potential in a given sensitive electronic system environment. It is not necessary that this uniform potential, say for a given system in a high-rise building, be the same as the earth potential at a given instance.

As more sensitive electronic systems (SES) face an increasingly hostile electromagnetic environment, grounding demands more care (St. John, 1992). In many industrial and commercial facilities, electrical grounding systems have become an unreliable signal reference because of noise pollution induced by high inductive reactance and electromagnetic interference (EMI). Matters have only worsened with the installation of local-area networks that rely on inexpensive cabling to transmit high-speed data. Unshielded cables are especially vulnerable to noise when signal levels are reduced to increase transmission speed. One effect is system lockup or freezeup, where the user's equipment fails to communicate with other system components, because it cannot transfer data without errors. According to the Electric Power Research Institute, Palo Alto, California, about 80 percent of EMI problems are due to conducted EMI generated within the facility; the remainder is generally attributed to the utility system. Radiated EMI

is becoming a major problem due to increases in emissions within facilities, and the use of more susceptible - higher frequency, lower signal strength - equipment and systems.

Quite ordinary building and plant systems can be a source of radiated and conducted emissions. Among those found in almost any building today are heating, ventilation and air-conditioning systems; elevators; fluorescent lights; office machines, especially copy machines; electric tools and appliances, and dimmer controls with non-linear converters that generate harmonics, electrical noise, and impulses. Factories add to this list with process controllers (with silicon controlled rectifiers, for instance), production machines, and arc welding machines. In hospitals, clinics and medical offices, radiology, electrosurgical, and diathermy units are likely culprits, while in offices with broadcasting equipment, FM, AM, TV, and radar transmitters are suspect. Finally, it may be possible to trace intermittent problems to the use of cellular telephones, police/emergency transceivers (walkie-talkies), or remote controls near sensitive equipment.

To prevent problems, equipment must be designed for compatibility with grounding concepts such as those described in the EIA/TIA-PN-2327 (TIA/EIA-607, 199X) or in Federal Information Processing Standards Publication 94, (FIPS PUB 94, 1983). Those whose job it is to install a new system must be familiar with the concepts in such works. Before presenting some theory on how grounding should be done as represented in an international Recommendation for grounding in central office buildings, the following excerpts from FIPS PUB 94 are presented as background material.

4.2 Grounding System

For more than 100 years of attention to lightning protection and power transmission fault control, electricians and electrical engineers have been exhorted to create and use low resistance ground connections to earth. This is appropriate for lightning and transmission line ground faults since part of their paths is through the earth. However, this is not the rationale for applying grounding principles to 120-, 240-, and 208-V utilization circuits. At these voltages, a system of interconnected or bonded conductors acting as a voltage reference network can equalize voltage differences throughout the network much more effectively than multiple low impedance earth contacts. Such an interconnected, bonded network can serve as both a power and signal reference, regardless of its voltage with respect to earth ground. However, to avoid shock hazards in a building structure and to minimize voltage differences between individual reference networks, it is not only accepted practice but mandatory for safety purposes that these networks be connected to earth ground. Since the connection to earth is never expected to carry load or fault current, the National Electrical Code (NEC) permits this conductor to be smaller than the equipment ground conductors in the network (Article 250-94 of NFPA 70, 1990).

If there are ground currents in a driven earth ground electrode from any source, a low resistance between earth and ground conductor with its attached electrode will help prevent generation of electrical noise which sometimes appears in coincidence with a high-voltage gradient in dried-out soil. If ground currents appear to be excessively high (more than an ampere or two in a residence to more than 20 amperes in a large building), it is advisable to determine the source of such currents and reduce its magnitude if at all

feasible to do so. High currents can cause deterioration of the electrode and become an increasing source of electrical noise.

Various functions and details of SES grounding may be summarized as follows:

- (1) Touch voltage differences must be limited by bonding and grounding to avoid shock hazard.
- (2) Ground fault current return path to power source must be low enough impedance to enable it to actuate overcurrent protection and disconnect the source.
- (3) Ground potential differences in the SES area must be reduced to essentially a constant potential reference.
- (4) Grounded conducting enclosures serve as electromagnetic shielding for sensitive circuits.
- (5) Grounding in compliance with safety codes is mandatory.
- (6) SES manufacturer's recommendations should be followed to the extent that they are consistent with item (5). Inconsistencies must be resolved.

Manufacturer's grounding instructions and recommendations are important and should be followed. Occasionally, however, the grounding techniques specified for various units are inconsistent, especially if they have been supplied by different manufacturers. Sometimes they are inconsistent with the interpretations of wiring codes by contractors, electricians, and inspectors. When there is doubt, there must be no compromise with safety. The system must be safe and must be capable of operating reliably without compromise.

4.3 Central Grounding Point

The Central Grounding Point of an SES system should be readily identifiable. It should be the point where the interconnected parts of the SES grounding are connected to other ground conductors which extend beyond and outside the Equipment Closet (EC). If there are two such points, each being interconnected to the other and to separate external grounds, the noise voltage difference between those separate grounds will cause noise current to flow through the SES ground system via the ground loop which is formed.

Within very large systems, there may be subsystems, each with a central grounding point for connection to other central grounding points. However, separate connections to separated external grounds would create unwanted external ground loops. By such means, impulse ground currents can find paths in the grounded shields and grounded conductors of signal pairs and coaxial cables. Intercoupling with digital circuits and signal corruption can be the unwanted results.

4.4 Frequency of Unwanted Signals

The frequency of noise signals (any signal other than the desired signal) can vary from dc to MHz and even GHz frequencies. Few detectors will respond to the entire spectrum and fortunately the digital circuits will not either. However, the trend in devices used in SES circuits is toward ever increasing bandwidth and lower signal levels (and lower burnout energies which cause the device to fail).

As signal frequencies reach and exceed approximately 10 MHz, radiation of the signals and coupling to adjacent circuits become increasingly troublesome problems. At frequencies above 30 MHz, concern over line conducted signals and noise becomes

overshadowed in importance by radiated signals and noise.

In today's technologies with digital data and control signals, any dc and low ac frequency (100 KHz or less) signal currents will follow the lowest resistance paths where conductors may be the largest and shortest. At high radio frequencies (above 100 KHz), stray capacitance and electromagnetic coupling become significant circuit paths. The path taken by dc currents could be tortuous (i.e., complex with parallel and series sections) and have too high an impedance to be a good high frequency path. At low frequencies (e.g., 60 Hz) where currents follow conductors, single point grounding is generally preferred. As signal frequencies exceed approximately 10 MHz and greater, the noise currents and voltage signals cannot easily be confined to conductors. In this realm, multipoint grounding becomes necessary if it is to be effective.

If the desired signal must be protected against both high and low frequency interference, a solid metallic galvanic grounding connection is needed for a single point ground, while at high frequencies one can use multiple ground paths via deliberate use of stray or discrete capacitors. A very effective technique is to have multipoint ground connections to an outer shield over an inner insulated shield which has a single point ground.

4.5 Single Point of Entry (Ground Window)

The single point of entry wiring strategy for SES rooms is a practical approach to establishing a virtual single point ground for the SES, the communication system, the power source, and the life-safety system. If all external conductors penetrating the SES room were to enter at a single point rather than at multiple points around the room, their

respective ground conductors could all be interconnected at the point of penetration. The expected benefit is that noisy ground currents flowing between the power, communication, and other ground conductors can flow through the short ground interconnections at the entry point rather than going through the grounding conductors within and among SES units. The remaining question is, "How short is short?" The answer depends upon signal frequency. The measuring yardstick is often related to wavelength of electrical signals. (Wavelength is approximately the speed of light divided by the frequency of a signal.)

Very short grounding conductors and interconnections are needed if they are to be effective at high frequencies. Not only does the typical conductor have inductance distributed along its length, but with the distributed capacitance there will be frequencies at which the conductor can become resonant with the high frequency noise or desired signal. Resonance considerations dictate that unless the interconnections can be shorter than 1/20th of a wavelength of the signal to be bypassed, its ability to conduct current will be impaired by partial or full resonance.

The "Earth Ground Connection" can be important to reliable performance of electronic circuits in SES, minicomputers, and microcomputers but its role is frequently misunderstood. As a result, much effort and sometimes needless expense is incurred in achieving a "quiet, isolated ground" with a very low ground resistance. The quiet, low-resistance attributes are always desirable, but a misunderstanding of the term "isolated" can lead to dangerous grounding practices which violate safety codes and will not necessarily solve noise problems.

Microcomputers, minicomputers, their peripherals, and other electronic office machines are typically powered and grounded solely by their three-prong grounding type 120-volt plugs on their power cords. If a sensitive electronic system (SES) or minisystem (e.g., one or more microcomputers, a printer, a modem, etc. contained in an office space) requires more than one separately powered unit, it is common practice to use a grounding type duplex receptacle, cube tap, or portable receptacle strip provided that the total load does not exceed 80% of the 15- or 20-A circuit protection rating for that circuit.

In many instances, such an arrangement has been used successfully. In its favor are having all minisystem grounds connected together at a common point as well as limited noise voltage differences appearing between this minisystem central grounding point and the grounding point for the power source's neutral or any conducting structural member or surface in the vicinity of the load. Unfortunately, there are often reasons why this may be marginally successful or not work at all:

- (1) The ground pin at the receptacle, the neutral grounding point at the building entrance service equipment, and the transformer power source's secondary output winding ground point are separated and may be grounded at two or three separate locations. This could permit noise voltages to develop between them and appear as common mode noise.
- (2) Older buildings may contain wiring without an equipment

ground conductor, and may even lack electrically continuous conduit to serve in its stead. If the outlet receptacle enclosure is grounded to a local water pipe, driven earth electrode, or building structural steel and there is no provision for an electrical return path such as an equipment ground conductor or continuous conducting path provided by conduit back to the power source grounding point, such an installation could be unsafe. It also may inject excessive electrical common mode noise current.

(3) The equipment ground conductor in the receptacle may be permanently connected to the conducting enclosure in which it is mounted. A connection which is integrally built into the receptacle normally creates this ground path. Noise currents originating from a load plugged into an adjacent or nearby receptacle could reach the sensitive equipment via this path.

4.6 Isolated Ground

One solution is to install an "isolated ground" receptacle (sometimes identified by orange color) in which the ground terminal is isolated from the mounting strap. An insulated equipment ground conductor is then connected from the grounding terminal of the receptacle in accordance with National Electrical Code Article 250-74 Exception No. 4 (NFPA 70,1990), and is passed through one or more panel boards without connecting to their grounding terminals (Article 384-20, Exception No. 1) for direct connection to the

applicable derived system or service grounding terminal. The equipment ground is connected to an independent earth electrode without any other connections to the building ground. The equipment grounding conductor from the receptacle with the isolated ground must be connected directly to the neutral grounding point for the building. This is necessary for safety, compliance with code, and for low electrical noise at an SES unit.

(Note by editor: This isolated ground approach may result in long leads that reach from the equipment to the independent earth electrode and the power neutral ground at the first disconnect point. The inductance of a long straight wire is about 1 microhenry per meter. At high frequencies, this can produce a large voltage drop between the equipment and earth ground.)

4.7 Grounding Myths

One myth about earth grounds makes them appear to be analogous to cesspools, allowing unwanted noise current to be drained into the earth and dissipated. If the ground current is small, one rod will do. If it is large, one must install a very long ground rod, install multiple interconnected rods, or create a buried grid of conductors over a large area like a leach field for sewage effluent. Treatment of the soil with water and chemical salts further decreases the ground resistance and enables the ground connection to earth to carry more current with less voltage drop. This information on how to create a low resistance earth connection is not myth. However, the myth is that all noise current can be drained away and dissipated into the earth. This can be true for lightning induced noise where the earth is one of the terminals of the lightning current path. In most other instances, the earth is not or should not be one of the terminals of a noise source. Electricity flows in circuits. It follows Kirchhoff's laws (what

current goes in must come out, and generated voltages equal the voltage drops).

The appropriate solutions are either to eliminate the source of the ground current or to provide short, low impedance paths where that current can flow safely without creating significant voltage drops or unwanted coupling into signal circuits.

Another myth is that SES requires a "clean, dedicated, isolated ground" with no electrical connection whatsoever between it and the "dirty ground." The term "dirty" is often used to describe the ground rod used for the utility power neutral ground where it enters the building, or a downstream isolating or stepdown transformer within the building. This myth has been responsible for a number of unsafe installations and code violations, plus needless expense for additional grounding rods and long, heavy gauge copper grounding conductors to "clean ground" locations placed far away from the "dirty grounds."

It must be stressed that earth electrodes should not be normal paths for ground fault currents in SES load utilization circuits. However, there may be some sources of ground current in driven earth electrodes associated with the power source. Lightning and switching transients are examples. Driven earth rods at various points along the neutral will have potential differences between them, thereby providing a source of ground current in these grounds and other grounds which are interconnected with them.

4.8 Earth-Electrode to Ground Resistance

Depending upon the amount of current flowing in a grounding rod, the need for low rod-to-earth effective resistance will vary. If only a few milliamperes are flowing, a 25-ohm ground would most likely be low

enough. If many amperes are flowing, it would be important that the heat loss about the grounding rod would not be so great as to dry out the soil and cause the ground resistance to rise. If this occurs or if too much current causes a high voltage drop in the soil around the rod, the back voltage is often rich in electrical noise which is unwanted in SES sites. The solution is to find and reduce the source of the ground current, if feasible, or add more parallel grounding rods.

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CHAPTER V GROUNDING AND BONDING PRINCIPLES

Historically, grounding system topologies in telephone networks evolved in two principal directions. The Common Bonding Network (CBN) topology is primarily used for transmission equipment. In many countries the Isolated Bonding Network (IBN) topology is preferred for switching equipment (Korbel and Tullius, 1991).

The following definitions have been introduced by CCITT (CCITT Recommendation K.27, 1990):

Bonding Network (BN) is a set of interconnected conductive structures that provides an electromagnetic shield for electronic systems and personnel at frequencies from dc to low rf. The term "electromagnetic shield" denotes any structure used to divert, block or impede the passage of electromagnetic energy. All BNs considered in this report are connected to earth; i.e., they are grounded. Many present-day documents refer to BNs as planes, zones, networks or systems.

Isolated Bonding Network (IBN) is a bonding network that has a single point of connection (SPC) to either the Common Bonding Network (CBN) or another Isolated Bonding Network (IBN). Existing documents refer to IBNs as isolated planes or isolated zones.

Common Bonding Network (CBN) is the principal means for effecting bonding and grounding inside a building. It consists of metallic components, structural steel, reinforcing rods, metallic plumbing, ac power conduit, cable racks, bonding conductors, etc., that are intentionally or incidentally interconnected. Various documents refer to

CBN as integrated plane, integrated zone or building grounding system.

Although there are differences in details, the currently used grounding and bonding topologies fall into one of the following generic categories:

Star-IBN is a type of IBN comprising clustered or nested IBNs sharing a common SPC (see Figure V-1a).

Mesh-IBN is a type of IBN in which the components of the IBN are intentionally interconnected to form a mesh-like structure. The mesh is insulated from the surrounding CBN except for a single-point connection (see Figure V-1b).

Mesh-BN is a bonding network in which all associated equipment, e.g., frames, racks, cabinets and usually, the Battery Return conductor are bonded together as well, at multiple points, to the CBN (see Figure V-1c).

5.1 Summary of Theory [Note: The following excerpts are taken from CCITT Recommendation K.27. This international Recommendation represents the most available, non-proprietary source known to the editor.]

Bonding and grounding (or earthing) refers to the construction and maintenance of Bonding Networks (BNs) and their connection to earth. In this report the acronym BN implies that a connection to earth exists. Also, BN is used to refer to CBNs and IBNs collectively.

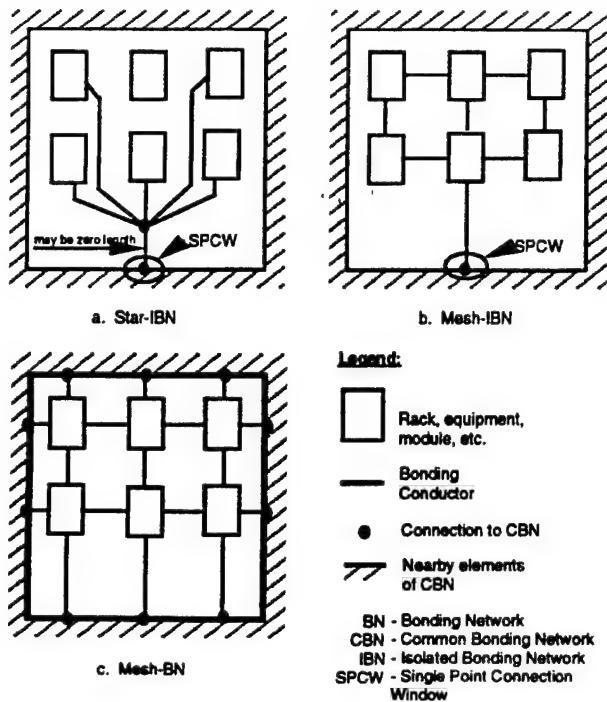


Figure V-1 Connection of Equipment Configuration to CBN [after Korbel and Tullius, 1991]

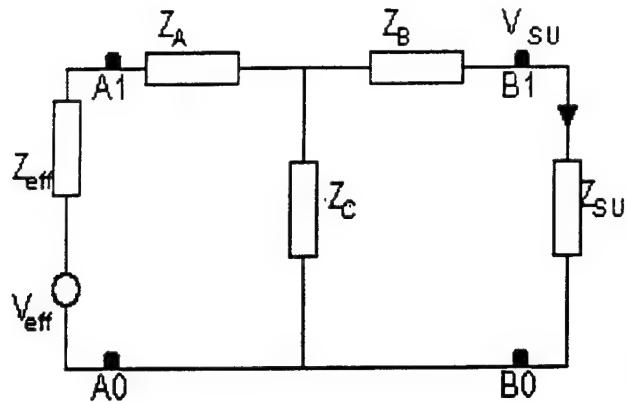
The primary purpose of a BN is to help shield people and equipment from the adverse effects of electromagnetic energy in the dc to low rf range. Typical energy sources of concern are lightning and ac and dc power faults. Of generally lesser concern are quasi steady-state sources such as ac power harmonics and "functional sources" such as clock signals from digital equipment. All of these sources will be referred to generically as "emitters". People and equipment that suffer adversely from the energy from the emitters will be referred to as "susceptors". The coupling between a particular emitter and a particular susceptor may be characterized by a transfer function. The purpose of a BN is to reduce the magnitude of the transfer function to an acceptable level. This may be

achieved with an appropriately designed CBN or CBN-IBN combination.

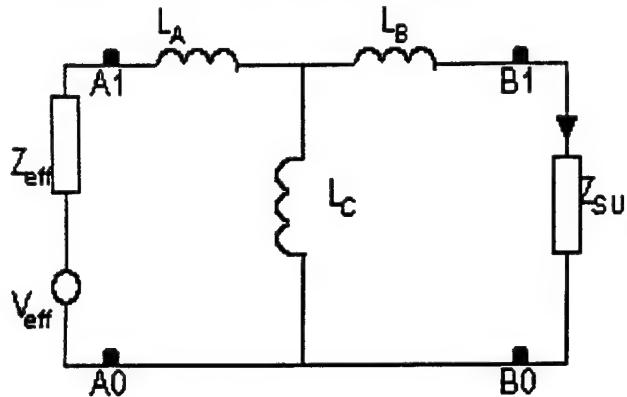
Other purposes of a BN are to function as a "return" conductor in some signaling applications and as a path for power fault currents. The capability of the BN to handle large currents helps to rapidly de-energize faulted power circuits. Also, the BN and its connections to earth are used in "ground return" signaling.

5.1.1 Brief Theory of Bonding and Earthing Networks

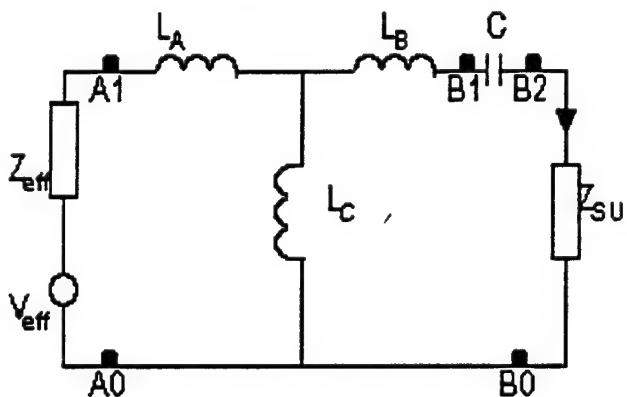
The basic theoretical notions of shielding apply to the entire electromagnetic spectrum extending from dc through microwave frequencies. The essence of these basic notions is represented by the circuit model of V-2. The description of energy sources as "emitters", and susceptible equipment (and people) as "susceptors" is taken from Keiser (Keiser, 1987). In Figure V-2a, V_{em} is the frequency domain representation of the emitter (e.g., a Laplace or Fourier transform), and Z_{em} is the emitter source impedance. The susceptor is represented by its impedance Z_{su} . The electromagnetic interaction between emitter and susceptor is modelled by a two-port network (port A with terminals A0, and A1, and port B with terminals B0, and B1). In Figure 5-2a this two-port is represented by a T-network, but a pi-representation is often useful, as a Norton equivalent, for the emitter. Although this figure is a



a) Fundamental Shielding Model



b) Shielding Model for Intra-CBN Coupling



c) Shielding Model for CBN-IBN Coupling

Figure V-2 Shielding Models for Grounding and Bonding (after CCITT K.27)

infinite in magnitude (i.e., open circuit), no emitter energy will reach the susceptor (and again $V_{su} = 0$.) In this case, the energy that

leaves the emitter is reflected by the open circuit. Suppose Z_B is the open circuit; then $Z_B = \infty$, and the energy will dissipate in the resistive parts of Z_{em} , Z_A and Z_C . Note that, in general, V_{su} and all impedances are functions of frequency.

A most useful characterization of the shielding network is a frequency domain transfer function. For each emitter-susceptor pair there is a transfer function that characterizes the shielding network.

In general, perfect short and open circuits are not possible to achieve, since the best implementations possess inductance and capacitance respectively. As a result, instead of perfect shielding, the most that can be achieved is a transfer function whose magnitude is less than some prescribed value over some prescribed frequency range.

5.1.2 Application to BNs in General

In typical bonding networks, resistive components are small, and for transient events with spectra in the 1 kHz to 1 MHz range, the shielding network is primarily inductive. Consequently, the general representation of Figure V-2a reduces to Figure V-2b. As noted above, the specific component values depend on a particular emitter-susceptor pair. However, the L's in Figure V-2b are constants; they are not functions of frequency. An observation of fundamental importance is as follows: Increasing the number of conductors and interconnections in the BN (especially in the region lying between the emitter and susceptor) will, in general, reduce LC and hence reduce the transfer function of the BN relative to that emitter-susceptor pair. In the limiting case, the susceptor could be given near-total shielding by enclosing it in an unbroken enclosure of metal (i.e., a Faraday cage).

5.1.3 Some Important Features of IBNs

Isolated bonding networks use an open-circuit shielding strategy. However, because IBNs are invariably installed within an enclosing CBN, short and open circuit strategies operate in cascade as shown in Figure V-2c. Here, node B2 could, for example, represent the frame of an equipment (Z_{su}) that is isolated except for a single-point-connection to the CBN at node B0. Node B1 represents all of the immediately surrounding CBN metalwork. The capacitor C represents the capacitance between the equipment frame and the surrounding CBN. Figure V-2c shows clearly that for low frequencies $|T(\omega)|$ will be small (it has a zero at $\omega = 0$), but at sufficiently high frequency there will be one or more resonances where $|T(\omega)|$ will have maxima. In the neighborhood of these resonant frequencies, shielding will be poor. However, if there are no significant emitters in these spectral regions, or if the equipment has additional shielding that is effective in these spectral regions, then no malfunctions will occur.

(Examples of the equations required, and examples of bonding configurations are provided in the referenced Recommendation.)

5.2 Implementation Principles

5.2.1 Implementation Principles for the CBN

The theoretical concepts are confirmed by practical experience and lead to the general principles listed below. A consequence of applying these principles is that the number of conductors and interconnections in the CBN is increased until adequate shielding is achieved. Concerning the important issue of electric shock, the following implementation principles apply to mitigation of electric shock as well as to minimizing equipment malfunction. Electric shock is discussed further in Section 5.3.

a) All elements of the CBN shall be interconnected. Multiple interconnections resulting in a three-dimensional mesh are especially desirable. Increasing the number of CBN conductors and their interconnections increases the CBN shielding capability and extends the upper frequency limit of this capability.

b) It is desirable that the egress points for all conductors leaving the building (including the earthing conductor) be located close together. In particular, the ac power entrance facilities, telecommunications cable entrance facilities, and the earthing conductor entry point should be close together.

c) The facility should be provided with a main earthing terminal located as close as possible to the ac power and telecommunications cable entrance facilities. The main earthing terminal shall connect to:

- an earthing electrode(s) via a conductor of shortest possible length;

- the neutral conductor of the ac power feed (in TN systems); and

- cable shields (at the cable entrance) either directly or via arresters or capacitors if required by corrosion considerations.

d) The CBN shall be connected to the main earthing terminal. Multiple conductors between CBN and the main earthing terminal are desirable.

e) As contributors to the shielding capability of the CBN, interconnection of the following items of the CBN is important:

-metallic structural parts of the building including I-beams and concrete reinforcement where accessible.

-cable supports, trays, racks, raceways, and ac power conduit.

f) The coupling of surges into indoor cabling (signal or power) is reduced, in general, by running the cables in close proximity to CBN elements. However, in the case of external surge sources, the currents in the CBN will tend to be greater in peripheral CBN conductors. This is especially true of lightning down-conductors. Thus it is best to avoid routing cables in the periphery of the building. When this is unavoidable, metallic ducts that fully enclose the cables may be needed. In general, the shielding effect of cable trays (etc.) is especially useful, and metallic ducts or conduit that fully enclose the cables provide near-perfect shielding.

g) In steel-frame high-rise buildings, advantage may be taken of the shielding effects that the steel frame provides against direct lightning strokes. For cables extending between floors, maximum shielding is obtained by routing the cables near the center of the building. However, as implied above, cables enclosed in metallic ducts may be located anywhere.

h) Where the facility uses overvoltage primary protection on telecommunication wires, it should have a low impedance connection to the cable shield, if it exists, and also to the surrounding CBN.

i) Overvoltage protectors may be provided at the ac power entrance facility if the telecommunication building is located in an area where power lines are exposed to lightning. (The protectors should be bonded with low impedance to the CBN.)

j) Mechanical connections in a protection path of the CBN whose electrical continuity is questionable shall be bypassed by jumpers that are visible to inspectors. These jumpers shall comply with IEC (NEC for U.S.A.) requirements for safety. However, for EMC applications, the jumpers should have low impedance.

k) The CBN facilitates the bonding of cable shields or outer conductors of coaxial cables at both ends by providing a low-impedance path in parallel and in proximity to the cable shields and outer conductors. Thus, most of the current driven by potential differences is carried by the highly conductive members of the CBN. Disconnection of one cable shield for inspection should minimally affect the current distribution in the CBN.

5.2.2 Implementation Principles for a Mesh-BN

The main feature of a mesh-BN is the interconnection, at many points, of cabinets and racks of telecommunications and other electrical equipment, and also multiple interconnections to the CBN. A proven countermeasure to undesirable emission or reception of electromagnetic energy, especially at high frequencies, is a shield that totally encloses the electronic circuit. Effective shielding of cables, especially when the shields are extensions of shielding

cabinets, depends on shielding material, shield geometry, and especially the connection of the shield to the cabinet panels at which the shield terminates. Adverse effects may be caused by insufficiently low impedance in the CBN. Disconnection of the cable shield for inspection should minimally affect current distribution in the CBN (an indication of low current in the shield).

It is easy to add shielding to a Mesh-BN configuration. The need for additional shielding may arise, for example, if a broadcast transmitter were installed nearby.

If the coaxial outer conductor has multiple connections to the CBN, it may need additional shielding. If the shielding provided by a cable tray is insufficient, additional shielding may be provided by use of shielded coaxial cable ("triax"), enclosing ducts, or conduit.

Bonding methods, in increasing order of EMC quality are: screw fastenings, spot welds, and welded seams. The highest level of EMC shielding is provided by equipment cabinets and any sheet-metal enclosures within these cabinets.

5.2.3 Implementation Principles for an IBN

The main feature of an IBN is that it is isolated from the surrounding CBN except for a single-point connection where conductors entering the system block enter via the transition region between the IBN and CBN. (This transition region, known as the SPC window [SPCW], is defined in the standard: The interface or transition region between an IBN and the CBN. Its maximum dimension is typically 2

meters. The SPC bus-bar, or frame, lies within this region and provides the interface between IBN and CBN. Conductors [e.g. cable shields or dc return conductors] that enter a system block and connect to its IBN must enter via the SPCW and connect to the SPC bus-bar or frame.)

Within the confines of an IBN, the importance of multiple interconnections between cabinets and racks, etc., depends on the details of dc power distribution and signal interconnection. For example, if the dc power return conductor has multiple connections to cabinet frames, then multiple interconnection of cabinet frames and racks is desirable for the following reason: it will tend to reduce surge coupling in the event of a dc fault in equipment within the IBN.

Concerning cable shields of twisted pair cables: if a shield is left open-circuit at one end, while the other end is connected to the CBN, surges in the CBN may result in induced common mode surges on the pairs in the cable. If those pairs terminate on devices that can operate satisfactorily in the presence of a steady-state common mode (e.g., opto-isolators, transformers, or surge protectors), and if those devices can also withstand common mode surges, then there may be an advantage in having the electrostatic shielding afforded by an open-circuited shield.

In the case of coaxial cable, the outer conductor will, of necessity, terminate on the interface circuits at each end. Interface circuits containing transformers or opto-isolators may be

used to isolate the outer conductor from the surrounding BN.

5.3 Protection Against Electric Shock

A densely interconnected BN, together with its connection to earth, substantially reduces the likelihood of significant voltages appearing between adjacent metallic components. However, additional measures need to be taken, especially in regard to ac power distribution. (NEC discusses protection against electric shock, and installations should conform to its recommendations.)

5.4 Protection Against Lightning

A CBN conforming to Section 5.2.1 should adequately shield against lightning surges arriving at the building on conductors such as cable shields and power lines. However, in the event of a direct stroke to the building, the CBN may not provide sufficient shielding. Consequently, buildings without steel frames or reinforcements may require external lightning protection; especially so if the building has a radio tower on its roof. Concerning the protective measures against the effects of a direct lightning stroke to a building refer to IEC Publication 1024 [or National Fire Protection Code ANSI/NFPA 78, 1989]. Where necessary to further reduce risk, these protective measures may have to be enhanced, e.g. by conductive roof layers, closer spacing of down-conductors, interconnection of the reinforcement of concrete buildings, and interconnection of metallic facade elements. It is advantageous to introduce all conductive elements of service, e.g. cables and pipes, into the building at one location and in close proximity.

5.5 Functional Earthing

Telecommunication techniques sometimes use circuits for signaling with earth return, e.g., lines with ground start, three wire interexchange connection. Equipment interconnected by these circuits needs functional earthing. The signaling range is normally determined by the resistance of the current path. Most of this resistance is contributed by the earth electrode(s). The performance provided by the earthing network via the main earth terminal is generally sufficient for this signaling purpose (CCITT Handbook, 1976).

5.6 Power Distribution

Ac and dc power distribution in telecommunication buildings should be designed to limit coupling to telecommunication circuits arising from:

- mutual impedance of shared conductors
- mutual inductive coupling (especially during short-circuit conditions), and
- via common source impedances.

5.6.1 AC Power Distribution

It is recommended that the ac power distribution system in a telecommunication building be of type TN-S as specified by the IEC. (For additional information applying to U.S.A. power distribution, please refer to Appendix C.) This requires that there be no PEN conductor within the building. If the neutral conductor is bonded to the main earthing terminal, this conductor is otherwise given the same treatment as the phase conductors. Consequently, a three-

phase network in a telecommunication building is, physically, a five-wire installation.

It is recognized that a TT-type system is in use for public power distribution. However, this recommendation does not fully address bonding and earthing of such a system. If power is served to the telecommunications building by a TT-system distribution network, a separation transformer dedicated to that building allows for the recommended TN-S installation. Other methods not using a separation transformer are under study [by the CCITT].

To avoid interference caused by magnetic fields of currents on power cables, it is usual practice to separate telecommunication cables from unshielded power cables by at least 10 cm, even if both have partial shielding in the form of the recommended metallic support structure.

5.6.2 DC Power Distribution

In telecommunication buildings, dc power is generally distributed from a centralized dc power plant, with the positive terminal connected to the CBN. This polarity is chosen to minimize corrosion in the outside cable plant. There may be exceptions for specific transmission systems.

The dc power-return network may be connected to its surrounding BNs at a single point only. This case will be referred to as an "Isolated dc-return" system.

Alternatively, the dc-return may connect to the BN at multiple points (in which case some dc current will be conducted by the BN). This system will be referred to as a "dc-return common to a BN" and denoted by "dc-C-BN". Typical configurations are dc-C-CBN (dc-return common to the CBN), and dc-C-IBN (dc-return common only to an IBN). Also, a dc-return could, for example, traverse both the CBN and an IBN, and be common to the CBN but isolated from the IBN. This case is denoted by dc-C-CBN:dc-I-BN. Other more complicated interconnections of BNs and dc-returns are also in use.

The advantage of a dc-C-BN system is that it cannot support a dc-feed common-mode, and hence unwanted coupling via this mode cannot occur. On the other hand, there will be coupling between the BN and the dc-feed. The advantage of the dc-I-BN system is that it avoids BN to dc-feed coupling. However, it supports a common-mode and may introduce unwanted coupling. The choice between the two systems depends on the overall design strategy. Some recommendations are given below:

- A dc-C-CBN feed may be used in systems in which the dc-feed-to-CBN coupling has been minimized by the following measures:
 - dc feed conductors have large cross-sections enabling them to carry high currents with minimal temperature rise,

- voltage drop at maximum load current is low, and
- there is low source impedance, and low mutual impedance between the branches of the dc-feed system.

The use of a dc-I-feed results in a much lower dc-feed-to-CBN coupling and is preferable in dc distribution networks designed with:

- loads in more than one system of electronic equipment (e.g., shared battery plant), and
- loads that are sensitive to transients occurring during short circuit conditions.

5.7 Comparison between IBN and Mesh-BN Installations

The advantage of installing equipment in an IBN is that a high level of shielding is attainable from dc through tens of kilohertz or perhaps hundreds of kilohertz depending on the size of the IBN. The reason is that, within this frequency range, the single point connection between the IBN and CBN results in negligible current flowing between CBN and IBN. Some digital switches are designed specifically for installation within an IBN.

To limit the risk of electric shock between an IBN and the surrounding CBN, it is necessary to limit the size of the IBN (both horizontal and vertical extent). Passageways that form the boundary between IBN and CBN should have a minimum width imposed.

5.7.1 Disadvantages of IBN

Disadvantages of IBN installation are cable routing restrictions and the

additional expense (compared to Mesh-BN) of maintaining the isolation.

A disadvantage of the Mesh-BN installation is the need for quantitative design procedures and appropriate immunity data for equipment.

5.7.2 Advantages

The advantage of installing equipment in a Mesh-BN configuration is that equipment frames may be connected to the surrounding CBN without restriction. Also, shielded cables and coaxial cables may be routed, and their shields connected to cabinet frames, without restriction. If the CBN design and equipment susceptibility have been coordinated, the CBN provides shielding from dc through several megahertz. A Mesh-BN installation also has maintenance advantages as described in the next section.

5.8 Maintenance of Bonding Networks

One advantage of Mesh-BN installation is that small changes that occur in the CBN generally have only a small effect on its shielding capability. Moreover, when necessary, additional shielding may be obtained by introduction of additional conductors (e.g., equalizers, cable trays, and conduits). Such modifications are usually straightforward.

It is recommended that systematic verification be performed on all bonding configurations and earthing connections inside a telecommunications building.

5.9 Examples of Connecting Equipment Configurations to the CBN

The bonding configuration that is used depends upon the type of equipment to be connected to the CBN. Three examples are described in the Annex B of Recommendation K.27, namely:

Mesh-BN

Mesh-IBN with a Bonding Mat Configuration

Star, or sparse-mesh-IBN with isolation of dc power-return

5.10 Mesh-BN

A Mesh-BN is a densely interconnected BN in which equipment frames are an extension of the CBN and which uses a dc power system of type dc-C-MBN. Figure V-3 shows an example of this configuration.

5.10.1 Components of a Mesh-BN

In Mesh-BNs, extensive interconnection among the following conductive elements is recommended:

Cabinets and cable racks of telecommunications and peripheral equipment;

Frames of all systems housed within the telecommunication building;

The protective conductor (PE) of the NTN-S-type ac power installation;

All metal parts, which according to IEC Publications must be connected to the protective conductor (PE);

The main earthing terminal, including earthing conductors and earth electrodes; and

Each dc power return conductor along its entire length.

Multiple interconnections between CBN and each dc-return along its entire length is usually a feature of the Mesh-BN configuration. The dc-return conductor of such a configuration may be entrusted with the functions of protective conductor (PE) for systems associated with ac loads or sockets, provided that continuity and reliability complies with the IEC Publications [NEC for USA].

5.10.2 General Design Objectives

Safety requirements supersede all other requirements. To ensure continuity of bonding conductors, reliable connection methods shall be used, e.g., crimping, welding. However, if several options exist for fulfilling safety requirements, only that one shall be used which best coordinates with EMC requirements.

5.10.2.1 Non-Telecommunication Installations

Within the whole telecommunication building, there shall be no exception from the TN-S-type ac power installation. This requires that the neutral conductor (N) and protective conductor (PE) shall be connected at the main earthing terminal but nowhere else in the building, neither in permanently connected equipment, nor in equipment connected by plug and socket.

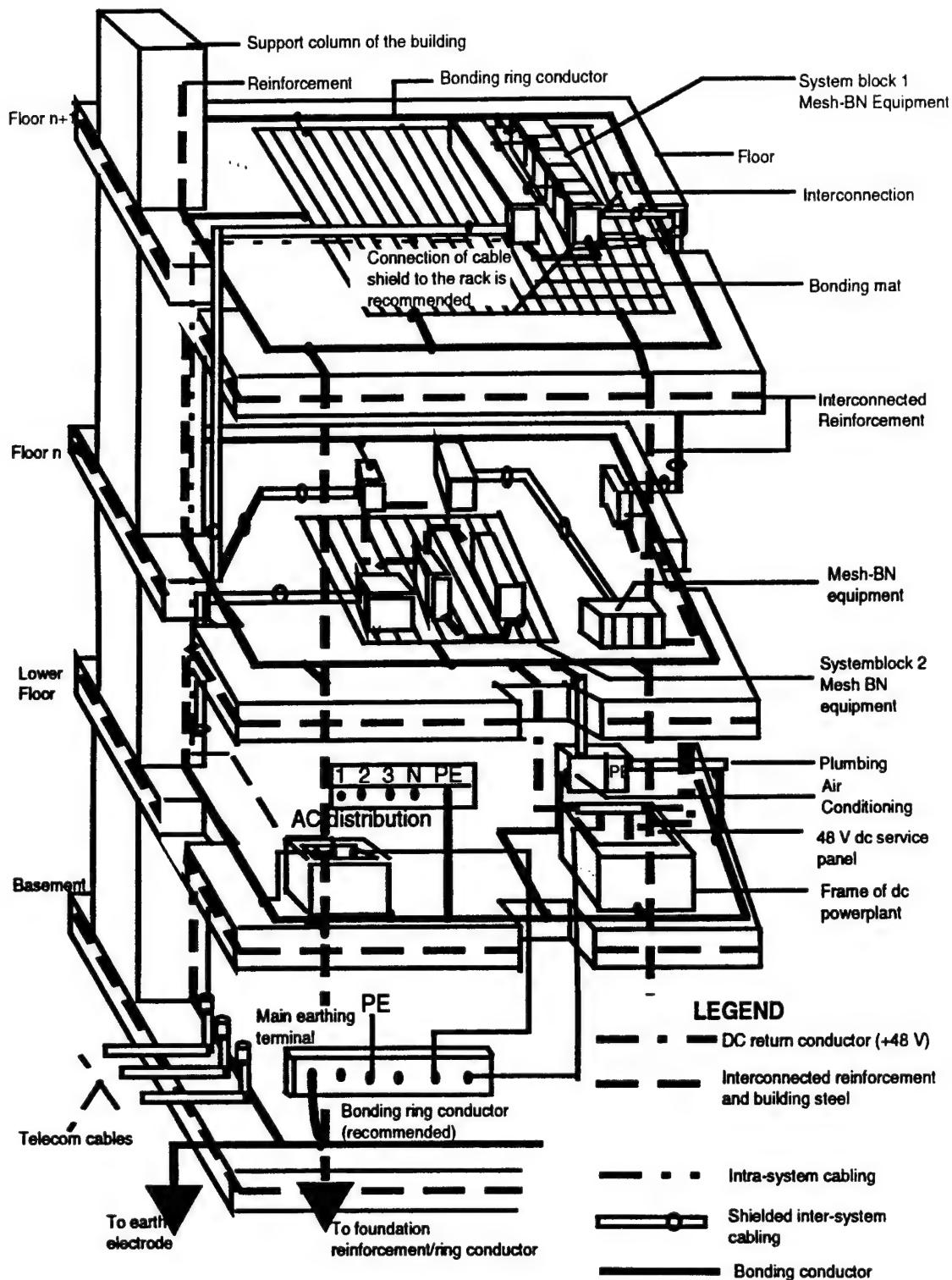


Figure V-3 Mesh-BN Installation Inside a Telecommunications Building (after CCITT K.27)

5.10.2.2 Telecommunication Equipment and Systems Telecommunication equipment with electronic circuitry is generally provided with a "potential reference" metallization that extends widely over the surface of the printed circuit boards (PCBs). If PCBs are connectorized, a number of pins are used to interconnect to adjoining cabling, backplanes, or motherboards. At this interface there starts the interconnection to the Mesh-BN via equipment frames, shelf-racks, etc.

The equipment racks shall be interconnected by low impedance leads or copper bars. Since the Mesh-BN technique usually incorporates the dc-return conductor into the CBN, the leads or bars can serve as the dc-return. The leads or bars of each row have to be interconnected via the shortest route to minimize inductance. One or more dc-return conductors may be used to interconnect the system to the centralized common power distribution cabinet or an intermediate power distribution panel. It is recommended that these leads be paired in close proximity to the corresponding negative dc power feed leads to reduce loop areas and enhance EMC. Small gauge dc power conductors should be twisted.

Dc/dc converters generally have one input conductor and one output conductor connected to the Mesh-BN. There may be exceptions in specific equipment.

An independent ac power supply network, derived from the dc supply by dc/ac converters, is best implemented as a TN-S-type.

Unrestricted fastening of the system to the floor and walls provides, in general, sufficient bypassing of stray capacitance for acceptable EMC performance of the system.

5.10.2.3 Cabling Regarding EMC, cables can act as antennas, and can support common modes that can transport extraneous energy into otherwise well-designed equipment. This antenna and common-mode propagation phenomenon can be mitigated by proper routing and shielding.

Routing of indoor cabling shall be in close proximity to CBN conductors and follow the shortest possible path. The shielding afforded by interconnected cable racks, trays, raceways, etc., shall be intentionally used. This shielding is effective only if it is continuous.

5.10.2.5 EMC Performance The use of dc power distribution with CBN return (i.e., dc-C-CBN), together with appropriate equipment design, is known to give acceptable EMC performance.

The incorporation of dc power-return conductors into the integrated-CBN limits voltage drops caused by short circuit currents in the dc power distribution network.

5.11 Mesh-IBN with a Bonding Mat Configuration

A high level of shielding may be obtained by connection of all equipment frames within a system-block into a bonding-mat configuration. This configuration is isolated from

the surrounding CBN. The result is a very effective type of Mesh-IBN.

The technical goals of this installation method are:

- a.) prevention of CBN currents from flowing in the bonding-mat or any other part of the system-block;
- b.) achievement of satisfactory EMC performance by controlled interconnection of system-blocks; and
- c.) provision of bonding and cabling facilities that allow for
 - systematic EMC planning;
 - and
 - use of well-defined and reproducible EMC test methods.

5.11.1 Equipment Configuration

The system-block comprises equipment agreed by the operating agencies and manufacturers to be interconnected to the mesh-IBN. (Note that this agreement facilitates assignment of responsibility to either the supplier or the operating agency.)

Peripheral Equipment: This denotes equipment located beyond the boundaries of the system-block, but which relies functionally on the connection to the IBN.

Equipment serving air conditioning, lighting, etc., is considered to be external to the system-block and may be installed and operated as part of the CBN of the building.

However, provision for the following is recommended:

- * protective earthing;
- * ac power distribution; and
- * dc power distribution up to the SPC, with the dc power-return conductors(s) incorporated into the CBN (dc-C-CBN).

5.11.1.1 Single Point Connection It is recommended that the SPC be established in the vicinity of its system, serving as the only connection between IBN and CBN.

5.11.1.2 Cabling All conductors and cables connecting to the system-block shall pass near to the SPC (i.e., through the SPC Window). Metalwork near the system-block shall be bonded to the SPC to avoid electric shock or flash-over in the event of a lightning strike to the building. Installation of a distribution frame at the SPC is recommended since this facilitates connection of cable shields to the SPC. It is recommended that the shields of all cables passing the SPC be connected to the SPC.

Alien cables crossing the area of the IBN must be spaced sufficiently away from cables connecting to the SPC and the system-block.

5.11.1.3 Equipment Powered by External AC Sources Equipment with IEC Class II certification (no PE connected) may be used without restriction within the system-block area or at its periphery.

Equipment with IEC Class I certification (relying on PE protection methods) shall be powered via isolating transformers, if not connected to dc/ac converters or ac power sockets belonging to the system-block.

5.11.2 EMC Performance

Digital telephone switches installed in bonding-mat IBN configurations are known to have satisfactory EMC performance.

Routing all connections to a system-block via a designated SPCW provides good access for the measurement of the conducted emission and susceptibility properties of a system-block by the use of clamp-on probes.

Under certain circumstances the EMC performance of an isolated system-block may suffer because of capacitive coupling between the system-block and the CBN or a neighboring IBN. This may permit high-frequency components of surge currents to flow, and also may permit electrical resonance effects to occur.

If dc power return conductors are not incorporated into the IBN of a system-block, the designer must take into consideration the voltage drop caused by short circuit currents conducted by the IBN to the SPC.

5.12 Star or Sparse-Mesh IBN with Isolation of DC Power Return

In this configuration, the framework of the switch is connected to form either a star or a mesh-IBN. (See Figure V-1). The cabinet framework and metallic panels are the major

component of this IBN (there is no bonding mat). This type of IBN (whether star or mesh) will be denoted by "Frame-IBN". The mesh topology is typically achieved by the cross-aisle interconnections afforded by cable trays. The result is a "sparse-mesh" IBN. The single point interconnection between a "Frame-IBN" and the CBN is made at the SPC bus-bar (SPCB) located within the SPC Window (SPCW). The SPCW has a fixed dimension that allows the SPCB to be of sufficient size for connecting conductors, while limiting the voltage drop across the SPCB in the event of lightning surges or power system faults.

The dc-feed section leaving the power plant is isolated (i.e., of type dc-I-CBN). This feed splits into an dc-I-IBN feed serving the Frame-IBN equipment (the system-block), and a dc-C-CBN feed serving integrated-CBN equipment. For the branch feeding the integrated-CBN equipment, a connection between dc-return and CBN is made at the SPCB. Beyond the SPCW, this branch is of type dc-C-CBN (i.e., it has multiple connections to the CBN). The dc-feed to the Frame-IBN equipment need not pass through the SPCW since within the Frame-IBN it is isolated. However, it is advantageous if most of the dc-feed cable is in close proximity to bonding conductors, because this will reduce surge voltages that appear across the isolation barriers of the dc/dc converters on which the dc-feed terminates.

To summarize, the main features of the system are:

*insulation of the Frame-IBN from the surrounding CBN;

*connection of the Frame-IBN to the CBN only at the SPCB; and

*isolation of the dc-return within the Frame-IBN and between the power plant and the SPCW.

Systems of this type (both star and mesh configurations) have shown satisfactory EMC performance.

Note that this example demonstrates how this bonding and earthing network combines, in one building, systems using IBNs and integrated-CBNs. The example also shows how all systems may share one dc power plant.

5.12.1 The DC Power Return Configuration

In the dc power system the Frame-IBN branch and the power plant branch are isolated, resulting in no conductive coupling from the CBN in these branches. However, surges (e.g., lightning and short circuit fault currents) arising in the dc-C-CBN branch (that feeds integrated-CBN equipment) can couple indirectly into the Frame-IBN equipment via the common source impedance presented by the power plant and the dc-I-CBN section. This impedance is kept to a low value by running the 48-V conductors and dc-return conductors in close proximity.

The bonding conductor from the SPCB to the frame of the power plant is run in close proximity to all dc feed conductors in the dc-I-CBN section. This reduces dc-feed common-mode surge voltages at the power plant and enables fault clearing in the event of a -48 V to frame fault in the power plant.

5.12.2 System Installation

Cable shields from outside the IBN that terminate within the IBN (i.e., on the system-block) have their shields:

- a) bonded to the Frame-IBN and to no other point (such cables shall not extend more than one floor from the SPC), or
- b) bonded to the Frame-IBN, bonded to the SPCB, and outside of the system-block, bonded to the CBN.

Subsystems that are part of the system-block should be colocated within one floor of the SPC of the main system. This avoids excessive voltage differences between the extremities of the IBN and nearby CBN.

Peripheral equipment that is to use an IBN and that is located more than one floor from the SPC of the main system shall use a dedicated SPC that is within one floor. The equipment shall be powered through an isolation barrier, e.g., by using dc/dc or ac/dc converters.

The isolation barrier inside any dc power equipment must have sufficient voltage withstand capability to meet local authority requirement. Installation and wiring of converters should comply with these isolation requirements.

Framework of equipment and metal structural components in a CBN that is located within two meters of an IBN should be bonded to the SPCB for reasons of personnel safety.

5.12.3 Maintainability of Isolated Bonding Networks

IBNs need careful installation and on-going surveillance to assure isolation. Also, the use of an isolated dc power-return may require on-going monitoring to check its isolation, especially if maintenance work is performed on different or mixed configurations by the same personnel. Violation of isolation during, or as a consequence of, maintenance work, may lead to failures in system operation or even to physical damage during lightning or power fault events.

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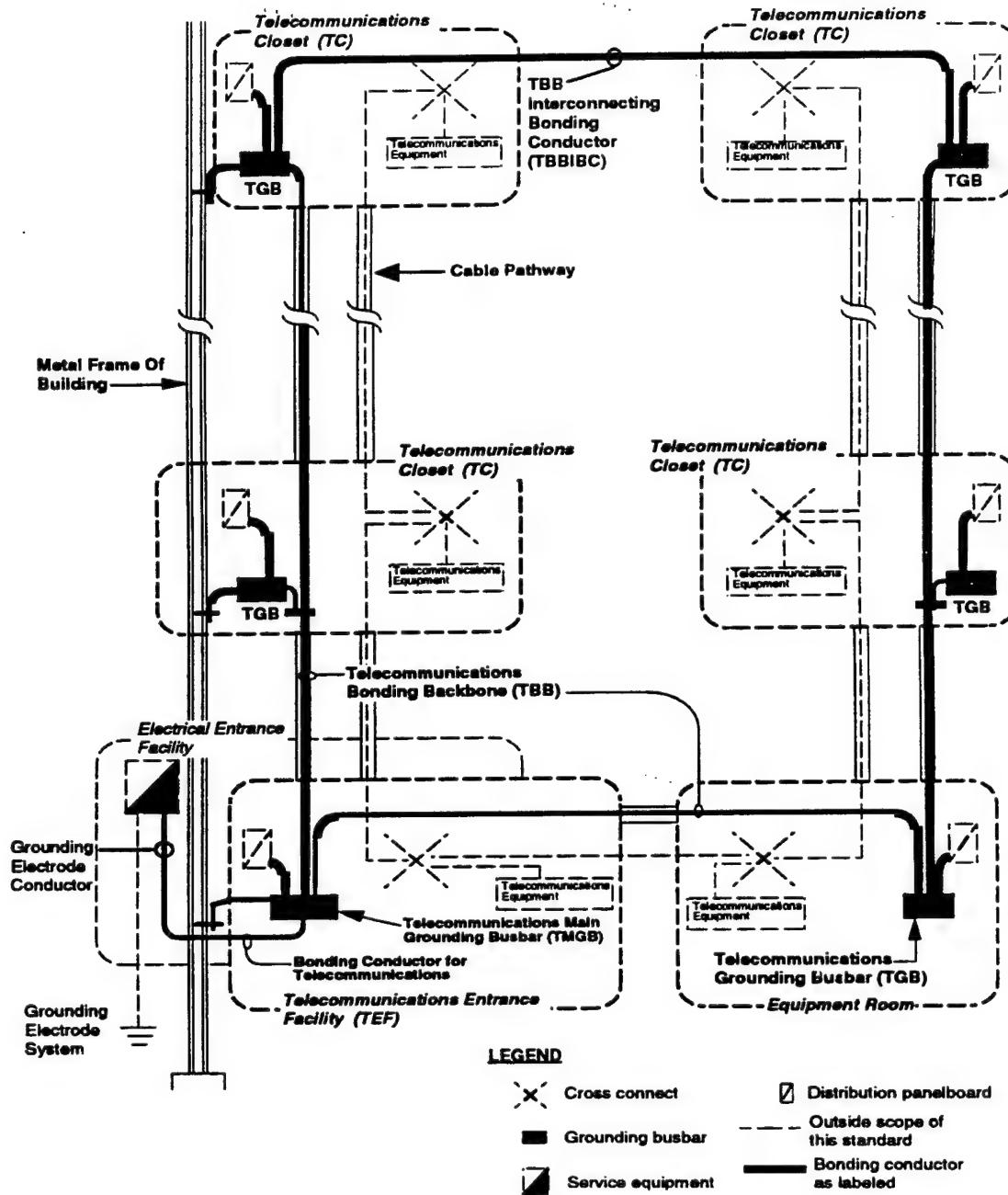
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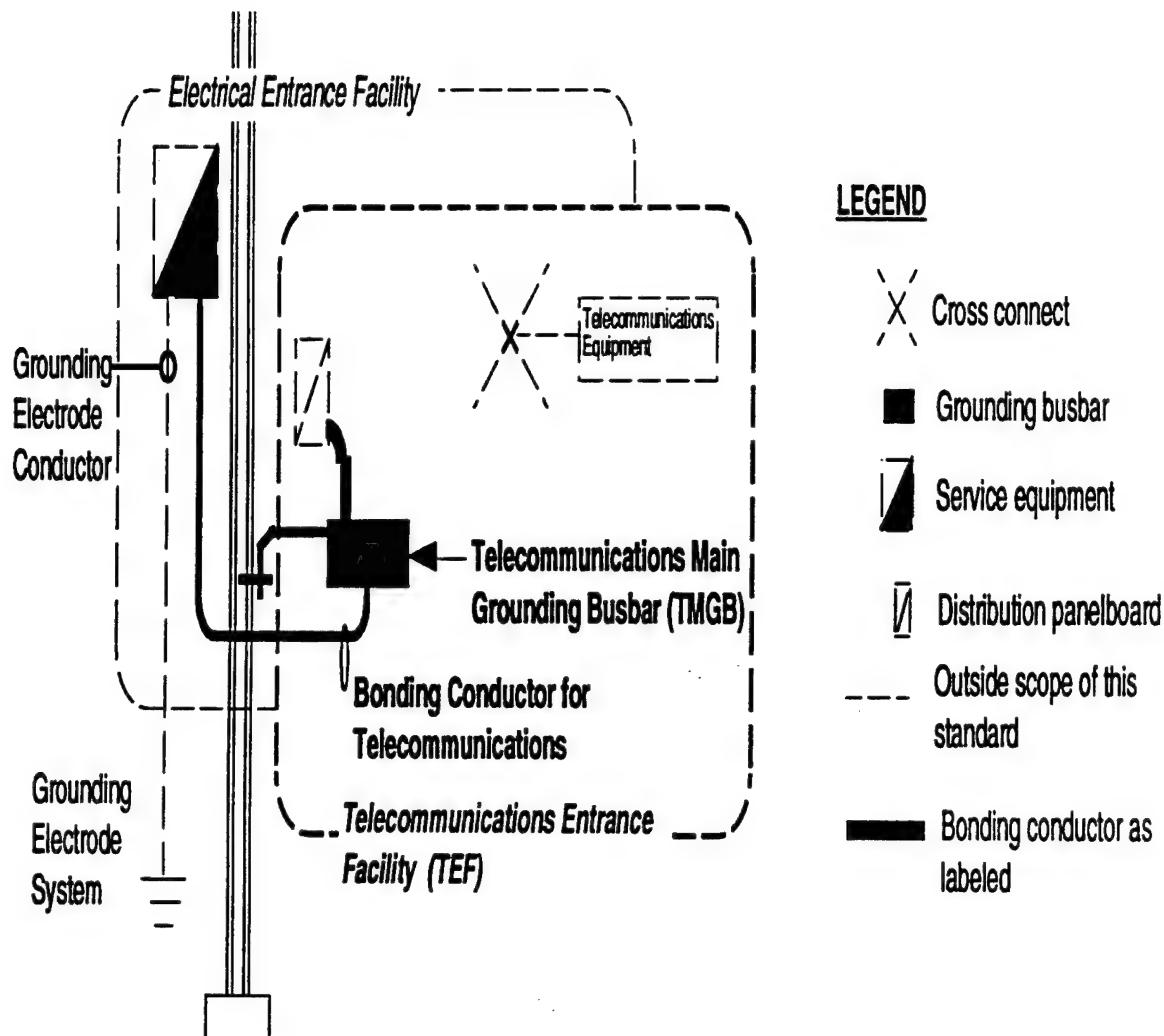
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This page is used to present a larger picture of
Figure III-4 Scope of the Standard for Large Commercial Buildings



This page is used to present a larger picture of
Figure III-5 Scope of the Standard for Smaller Commercial Buildings



CHAPTER VI GROUND WINDOW

6.1 Protecting Personal Computers (or Work Stations)

In a paper entitled "Protecting Computer Systems Against Power Transients" (Martzloff, 1990), the author indicates that for computer systems in the same room or corner of a building, the built-in capability of the units is probably sufficient to protect from damage. This might be a work area supported by a TC in our standards. For systems with longer reach, the ultimate protection is an optical fiber link with no metallic jacket, which provides immunity against noise collection as well as possible surge damage.

A mechanism that could cause trouble is the difference in the potential of objects at nominal "ground" potential occurring during surge events. Most data links operate with the signal reference conductor (shield or one wire of a group) connected to the chassis of the equipment. This chassis is in turn connected to the grounding conductor of the power cord supplying the equipment, a requirement of the National Electrical Code. Thus, if lightning or power system faults inject a high current in the site's ground conductors, the potential of the "grounded" points at the two ends of the data link differs. This potential difference causes a current to flow into the data link, possibly exceeding the capability of the input or output components.

The user can stay with conductors for the data link or convert (or initially design) it to an optical-fiber link, an approach that is becoming increasingly popular as hardware costs fall with economies of scale. However, if the conversion electronics at the ends of the fiber link are disturbed by electrical noise, that noise will be faithfully transmitted, not blocked.

If a conductive data link is to remain, the remedy is to insert protective devices that are complementary for the power line and data line. These devices typically operate by limiting the overvoltage or attenuating the higher frequencies by filtering, which works effectively on the power line but not on the data link. Here, filtering is not possible because it would affect the signals; limiting the overvoltages will eliminate that damage risk, but might still let through a spurious signal. Thus, data integrity may be more difficult to achieve unless the software includes inherent immunity or fault tolerance.

A mechanism can be demonstrated by a scenario that can occur in any building with power and telephone service. The incoming telephone line is provided with surge suppressors (carbon blocks or gas tubes) that divert surges to the nearest grounded conductor, generally a nearby water pipe. The manufacturer of the computer or modem used for the computer-telephone-line linkup may have provided a protective device within the equipment. Alternately, the surge-conscious user may have inserted a protective device in the power cord. But should a surge occur on either the data line or the power line, the corresponding protective device will dutifully divert that surge to the nearest ground. Since the "nearest ground" may not be the same for the connection of the two suppressors, the surge current in the ground connection raises the potential of one side with respect to the other, placing the data input at risk.

The solution is the application of the "ground window" concept developed by telephone companies in protecting their central station switches: all cables entering a room or a complete

floor in a building are routed through a single "window" where grounding conductors, shields, and ground connections of protective devices are bonded together. In this manner, there cannot be any potential difference between the various ground reference points within the room or floor.

A definition of Ground Window obtained from a Bellcore document (Bellcore, 1987) is:

A dimensional transition zone consisting of a [hypothetical] sphere with a maximum three feet radius, which is the interface between the building's integrated ground plane and a given isolated ground plane. It is the opening (a window, if you will) where all ac and grounding conductors (including metallic raceways) serving an isolated ground plane "see" their last connection to the building's integrated ground plane before they are connected to the isolated ground plane frames. Any bond or connection to the ground window shall be within three conductor feet of the center point of the sphere. Any number of individual isolated ground planes can be referenced to a single ground window.

After passing through the ground window, all the grounding conductors associated with the isolated ground plane are insulated from the building integrated ground plane because they have become a part of the isolated ground plane.

Conductors serving integrated ground planes that multiground the return side of the principal power source and are energized from the same power plant serving the isolated ground plane must be routed through and connected to the main ground bus inside the ground window. They do not have to be insulated from the building's integrated ground plane beyond the ground window.

6.2 Conceptual Layout of Building Wiring

The EIA/TIA-568-1991 standard defined the topology of the building wiring to be used in compliance with the standard. Beginning with this topology a building architecture was developed in EIA/TIA-569-1990. This standard was subsequently called Pathways and Spaces since it defines the several rooms (e.g., equipment rooms, telecommunications closets, and entrance rooms) as well as the pathways recommended for the routing of the wiring within the building. The intrabuilding elements are shown schematically in Figure VI-1.

6.3 EIA/TIA-568-1991 and CSA T529 DEFINITIONS

The topology of the horizontal wiring adopted in these standards is that of a star with each work area telecommunications outlet connected to a telecommunications closet (TC). The maximum distances for horizontal wiring is set at 90 M (295 FT). This distance is independent of the type of media used. The topology and distances supported by a telecommunications closet is shown in Figure VI-2.

Note that this topology provides a common entry (window) into the work area served by

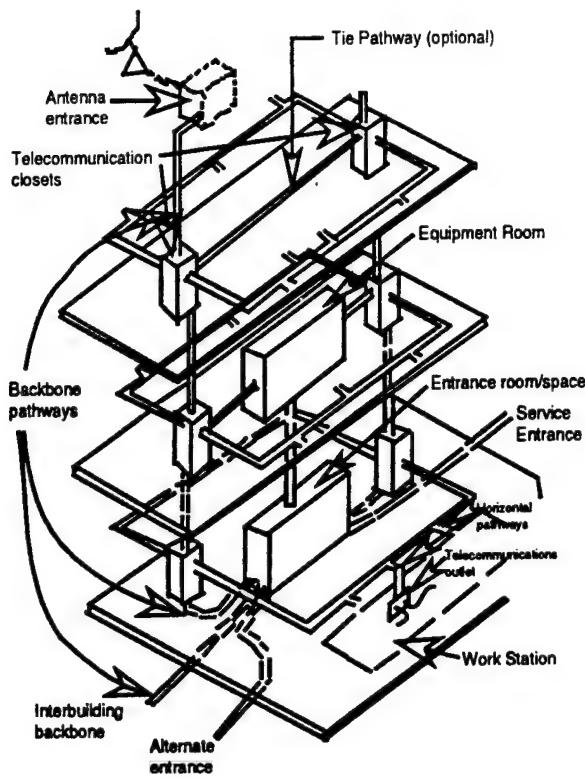


Figure VI-1 Conceptual Layout of Intrabuilding Elements [after EIA/TIA-569-1991]

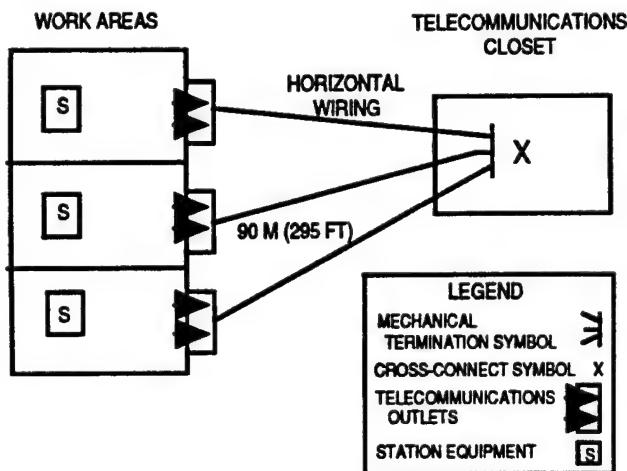


Figure VI-2 Topology and Distances for Horizontal Wiring [after EIA/TIA-568-1991]

the TC. If the power distribution for this work area also emanates from a position near the

closet so that a grounding window may be established through which the safety (green wire) power ground, the SES electronic ground and the telecommunications lines enter the work area, then an effective single point grounding system may be established. This ground window concept applies then to all systems served by the TC.

6.4 Single Point Grounding Tree Configuration

Any system served by the TC is effectively connected to a single point ground (SPG). No matter what the complexity of the systems in the work area, the telecommunications grounding system is as shown in Figure VI-3.

Each circle represents a group of equipment containing an isolated Bonding Network (IBN) in an area served by the TC.

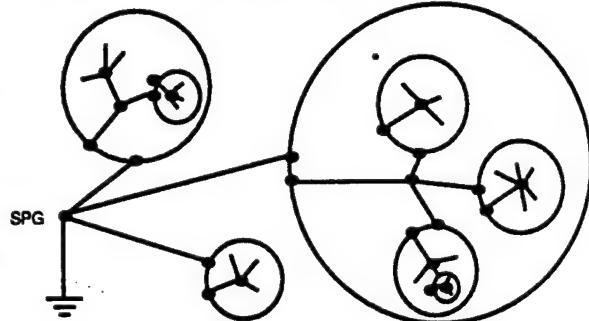


Figure VI-3 Single Point Grounding (SPG) Tree Configuration

Similar arguments apply to the Entrance Room/Space, Equipment Room, and Main Cross-Connect locations where the presence of a telecommunications backbone (TBB) and a telecommunications Grounding Bar (TGB) exist.

It is important to note that the interconnection of equipment served by different TC's must be made through the horizontal and backbone wiring and not by interconnecting cables between systems

even though they may be on the same floor and the interconnection distance may be shorter via a direct connection.

6.5 Conclusions for TR-41.7.2 Grounding Systems

Since only one ground window will serve a particular set of equipment, differences of potential caused by transients induced by lightning, radiation, etc. on the grounding system illustrated in Figure VI-4, will not flow into the systems except through the

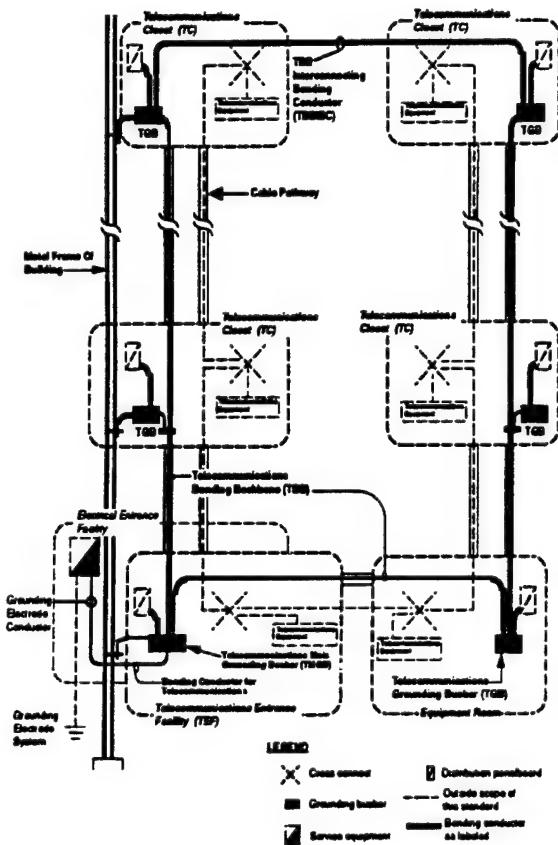


Figure VI-4 Telecommunications Grounding/Bonding [after TIA/EIA-607-199x]

grounding window. This will cause all of the elements served by the TC to rise or fall at the same time and rate and should not

introduce a signal current (error). If more than one ground connection is made to a system contained in the hypothetical spheres that surround the systems in Figure VI-3, then a possibility of currents flowing in the system resulting from the ground potential differences exist.

The grounding approach recommended in PN-2327 works conceptually for the wiring topology proposed in EIA/TIA-568-1991 and installed in accordance with EIA/TIA-569-1991.

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CHAPTER VII EXPOSURE

The following description of exposure is taken from T1Y1.4 document (91-016R3):

7.1 Sources of Unwanted Voltages and Currents

Telecommunications network plant serving customer structures or buildings is classified as exposed (T1Y1.4, 1992) to unwanted voltages and currents when subject to any of the following:

- (1) Disturbances from lightning
- (2) Contact with electric power circuits
- (3) Ground potential rise
- (4) Induction from electric power lines.

Any telecommunications network plant serving customer structures or buildings that is classified as exposed shall require coordinated electrical protection at the entrance to the customer structure or building.

7.1.1 Lightning Exposure

Telecommunications network plant serving customer structures or buildings is defined as exposed to lightning when any of the following is true:

- (1) Thunderstorm activity exceeds five (5) thunderstorm-days per year or earth resistivity is generally 100 meter-ohms or more as measured per IEEE Standard 81-1983, *Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of a Ground System*.

(2) The customer structure or building is located at elevations significantly above the average elevation of the surrounding terrain, such as hilltops.

(3) The customer structure or building has radio antennas/towers on the roof or is adjacent to tall structures such as towers or water tanks.

Telecommunications network plant serving a customer's structure or building is not safe from lightning exposure solely because it is located below the earth's surface. A buried or underground telecommunications service wire or cable can become a conductor of lightning currents resulting from nearby strokes to the earth.

7.1.2 Power Contact Exposure

Power and telecommunications companies often serve the same customer structures or buildings. Both companies frequently employ joint-use or common facilities such as poles for aerial plant or a common trench for buried plant. Telecommunications network plant is considered exposed to power contact when the possibility exists for contacting a power conductor operating at 300 volts rms or greater to ground. Telecommunications network plant that is directly buried in the same trench with power in excess of 300 volts rms to ground with no deliberate separation shall also be considered exposed to power contact. Contact may result from a falling phase conductor in aerial plant, or a dig-in in buried plant.

7.1.3 Ground Potential Rise

Ground potential rise may occur during a power fault when fault current returns to the

power neutral through the earth. Telecommunications network plant serving a customer structure or building is considered to be exposed to ground potential rise if the possibility exists that local ground may differ from remote earth by 300 volts rms or greater as determined by ANSI/IEEE 367-1987, *The IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault*.

7.2 Sources of Exposure At Customer Structures and Buildings

For the purposes of this report, the customer structures are the Commercial and Government buildings under discussion.

7.2.1 Exposed Telecommunications Network Plant

Telecommunications network plant facilities shall be classified as exposed if they serve a customer location that is classified as exposed to lightning or commercial ac power as detailed in 7.1, above.

7.2.2 Exposed Commercial AC Power

Telecommunications network plant serving the customer location shall be classified as exposed to lightning if the commercial ac power service is exposed to lightning.

7.2.3 Exposed Customer Sites and Antennas/Towers

By their very nature, radio antennas/towers may expose a customer location to the damaging effects of lightning.

7.3 Exclusions

7.3.1 Lightning

Telecommunications network plant serving customer structures or buildings should be

classified as unexposed to lightning if located in an area treated as unexposed by the owning utility. The latter area may be a metropolitan location having a high density of multistory buildings and an extensive network of buried metallic piping systems and cables. In these areas, lightning-induced surges are unlikely to enter the customer structure or building through the serving telecommunications cables which are effectively shielded and grounded. Although the customer structure or building itself may not be within the zone-of-protection of a higher structure (see ANSI/NFPA 78-1989, *Lightning Protection Code*), the risk of damage from a direct lightning stroke is accepted as a low probability event.

7.3.1.1 Short Below-Ground Cable Runs

Where a zone-of-protection is not present, short buried or underground cables not exceeding 150 feet in length and having a continuous metallic shield that is properly grounded at both ends should be considered as unexposed to lightning. Examples are campus environments having short interbuilding cables, or a remote subscriber loop carrier hut serving a customer's structure or building.

7.3.2 All-Dielectric Cable

All-dielectric optical fiber cable is excluded since it contains no metallic members. However in locations exposed to lightning, buried cable may be subject to mechanical crushing damage due to arcing of lightning to nearby underground metallic objects.

7.4 Electrical Protection Considerations

(Although electrical protection has not been included in the TIA/EIA-PN-2327 document, the following excerpt from the subject T1Y1 document may be useful in this background report.)

7.4.1 General

Electrical protection measures include the bonding and grounding of metallic members of telecommunications network plant (paired-conductor cable, optical fiber cable, service wire) serving the customer structure or building. Electrical protection may include isolation techniques where appropriate. In addition, a listed protector (listed for the purpose by a Nationally Recognized Testing Laboratory) shall be applied to entering metallic pairs under the following conditions:

- the telecommunications network plant, serving ac power or the customer location is exposed to lightning
- the telecommunications network plant is exposed to possible power contact or induction in excess of 300 volts rms to ground
- the customer location is exposed to possible ground potential rise in excess of 300 volts rms with respect to remote earth.

When exposure to power contact greater than 300 volts rms to ground exists, a fuse link shall be applied in the telecommunications network plant in addition to the protector.

7.4.1.1 National Electrical Code Considerations

Articles 770 and 800 of ANSI/NFPA 70-1990, *National Electrical Code*, cover the installation of telecommunications facilities at customer's structures or buildings. However, the National Electrical Code (NEC) does not cover installations of communication equipment under the exclusive control of communication utilities, located outdoors or in building spaces used exclusively for such installations (see NEC Article 90-2 (B) 4). Grounding is covered in Article 250 of the NEC.

The NEC distinguishes between optical fiber cables that contain metallic pairs and those that do not. Those that contain metallic pairs are treated as communication cables per Article 800; those containing no metallic pairs are treated as optical fiber cables per Article 770.

Requirements of the most recent edition of ANSI/NFPA 70, *National Electrical Code*, shall be met except where superseded by local electrical codes.

7.4.2 Grounding

Grounding provides a means for removing unwanted electrical energy (lightning, ac power influences) from metallic members. The application of protectors to telecommunications pairs provides a means to divert unwanted electrical energy to ground.

7.4.3 Bonding

The objective of bonding is to equalize potential between conductive parts such as between telephone and ac power service grounds, or between metallic members of multiple telecommunications cables entering a customer location.

7.4.4 Protectors

Protectors limit the voltage difference between telecommunications pairs and ground by providing a path to ground when the operating voltage of the protector is reached. Typically, protectors are equipped with carbon block or gas tube protector units. These units typically limit the voltage between conductor and ground to 1000 volts peak (see ANSI/IEEE Standard C62.61-1985, *Gas Tube Surge Arresters on Wire Line Telephone Circuits*).

7.4.5 Fuse Links

A fuse link is intended to limit current, under power contact conditions, to a value that can be safely carried by the protector. Under

certain conditions where fuse links can not be provided, fused protectors shall be used. A fuse link is not intended to protect cable or the customer structure or building from lightning damage.

7.4.6 Isolation Techniques

DC currents that are present in the earth from such sources as dc traction systems (e.g., trolley or railway), pipeline protection systems, or dc transmission systems, may contribute to the corrosion of grounded telecommunications plant and hardware. Insulating joints, which interrupt the metallic members of entering telecommunications cables and prevent the flow of dc currents, should be installed to mitigate the corrosive effect of the dc currents (electrolysis). On the customer side of the insulating joint, the metallic members of all entering cables shall be bonded together and grounded to an acceptable ground. On the telecommunications network side of the insulating joint, the metallic members of all entering cables shall be bonded together, and all metallic members and associated metal shall be deliberately isolated from ground. A bond shall not be placed across the insulating joint. However, insulating joints may be bridged with capacitors to permit alternating currents and lightning surges to flow to ground. Conductors equivalent to No. 6 AWG or coarser copper should be used for bonding and grounding at the insulating joint.

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(Updated June 16, 1992)

[The following document register represents all of the contributions presented to or made by the standards working group TR-41.7.2 to the date shown above.]

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92-06-072 Contribution entitled Rewrite Sections 1 and 2, and 4, June 15-16, 1992, submitted by M. Meister

APPENDIX B

FOREWORD

This appendix consists of a published paper by the author. (The author has both Bachelor and Master of Science degrees in Electrical Engineering and has worked mainly in the field of Engineering Physics since 1952. From July 1970 to November 30, 1990, he worked for the U.S. Department of Commerce, National Telecommunications and Information Administration, Institute for Telecommunication Sciences, Boulder, Colorado.) This paper is included to provide a perspective of the potential needs for building grounding in an end-to-end protected telecommunications network. Not all Commercial or Federal government buildings will require the extra protection described here but the source(s) of disturbances are outlined and a bibliography of reports is presented that may permit interested readers to look further into the problems associated with grounding and, particularly, shielding as defined for many Government buildings.

The material described in this Appendix was used by the author to provide several briefings to EIA TR-41.8.1 and EIA TR-41.8.3 to convince these standards bodies that additional work was needed for Commercial buildings that contain sensitive electronic equipment.

The author would like to express his appreciation to the management of EIA/TIA and to the subsequent working groups (particularly, EIA/TIA TR-41.7 - Environmental and Safety Considerations of the TR-41, User-Premises Telecom Requirements) that undertook the development of ANSI standards in this area. A special word of appreciation to Mr. Jim Romlein, Midwest Integrated Systems Laboratories, Inc., who has chaired the work under TR-41.7.2 - Bonding and Grounding and to Michael Meister, National Telecommunications and Information Administration, Institute for Telecommunication Sciences, U.S. Department of Commerce, who has acted as the secretary for this working group and who has prepared many drafts of the resultant proposed standard.

TELECOMMUNICATION BUILDING GROUNDING SYSTEMS

by

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ABSTRACT

Grounding systems for buildings containing sensitive telecommunication systems require planning at the architectural level and require care in the building construction. The extent of the changes in existing building practices will be dictated by the intended use of the building. Currently, building grounding systems generally are designed to provide personnel safety both from transient induced voltages and currents, such as those produced by lightning, and from unintentional contact of power leads to exposed surfaces, such as equipment racks or cabinets. In addition to these safety features, an effective telecommunication building grounding system will maintain equipotential between all conductors in the building over a very wide frequency range. This paper describes five grounding subsystems, namely: earth electrode, lightning protection, fault protection, signal ground, and transient protection.

INTRODUCTION

Building grounding systems in general are designed to provide personnel safety both from transient induced voltages and currents, such as those produced by lightning, and from unintentional contact of power leads to exposed surfaces, for example equipment racks or cabinets. Equipment protection is a subset of this requirement for building grounding. Equipment protection has become much more important with the introduction of

highly sensitive (and highly vulnerable) electronic systems, such as networks of computer terminals, in most buildings. This new equipment requires special grounding and protection considerations to prevent operational upset or burnout from transient induced voltages and currents and to eliminate the introduction of significant electrical noise.

Transient induced voltages and currents may be either conducted into the building via power lines, communication cables, or utility penetrations or radiated into the building in the form of electromagnetic pulse [e.g., that produced by lightning or by a nuclear event external to the earth's atmosphere [High Altitude Electromagnetic Pulse, (HEMP)]]. A primary consideration in meeting the objective of the grounding system for the conducted transients is to assure that all conducting media, e.g., power, water mains, communication wiring and cables, etc., enter the building through a single building entry point. This will help to prevent the buildup of voltage potentials between elements of the grounded media within the building. Protection against electromagnetic radiation will require shielding of cabinets, rooms, or buildings with careful control of penetrations of such shielding. It is very important that grounding be considered as part of the building design and construction in order not to preclude the adequate protection of telecommunications, computer, and other sensitive electronic installations in commercial and public buildings.

OBJECTIVE

To provide an effective telecommunication grounding system that will maintain equipotential between all conductors in the building over a very wide frequency range.

BACKGROUND

The primary source of external transients that may cause catastrophic failure of telecommunications equipment is lightning. Lightning is characteristically a point phenomenon that causes large electrical currents to flow in conducting media that may penetrate the building. It may also cause extremely high currents and voltages to be induced by a direct strike on a building. Lightning strikes also produce electromagnetic pulses that radiate into the building and interact with wiring and equipment in the building.

Another source of external transients that provide a major threat to telecommunication environments is that produced by high-altitude (nuclear) events (Hull, 1987). Such events are of major concern in buildings to be occupied by agencies such as public safety, public health, and agencies responsible for functional continuity of government. The potential of this threat being executed by terrorist interests appears to be growing. The time waveforms and spectral characteristics (Antinone, 1987) of the lightning, and HEMP phenomena are shown in Figure B-1. The magnitude of the HEMP pulse is far greater than that from lightning and the rise and decay times are much faster, resulting in broader spectral content. The other primary difference is that the HEMP phenomenon is a plane electromagnetic wave radiated by a very large source region at the top of the atmosphere; consequently, it may cover a

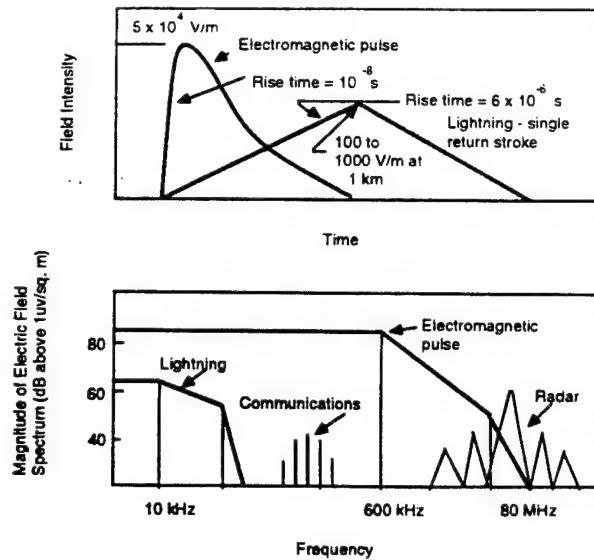


Figure B-1 Time and Frequency Waveforms for Lightning and HEMP

very large area (e.g., the continental United States) whereas the pulse resulting from lightning is generally a local event. Mitigation of the effects of these threats requires many of the same methods as those used for lightning protection, but devices must react to faster rise time pulses. The shielding for the HEMP must be much more thorough than that required to shield against lightning radiation (Messenger and Ash, 1986).

GROUNDING SUBSYSTEMS

The telecommunication building grounding system of interest to the building architect or designer is made up of the following subsystems (Bergman, 1988):

- 1) Earth Electrode Subsystem
- 2) Lightning Protection Subsystem
- 3) Fault Protection Subsystem
- 4) Signal Ground Subsystem
- 5) Transient Protection Subsystem

Earth Electrode Subsystem

The earth electrode subsystem should be as illustrated in Figure B-2 in order to assure adequate contact with the earth surrounding the building, (Bergman, 1988; Phelps and Pullen, 1988). The ground rods are connected to a minimum #2 AWG loop to provide a ring ground. The ring of this ground should be buried a minimum of 30 inches (ANSI/NFPA 70, 1987). If the soil conditions are such that the ground rods cannot be driven, this ring ground may be replaced with a buried grid that may be located under the building or in a central location for a complex of buildings that use the same electrode subsystem.

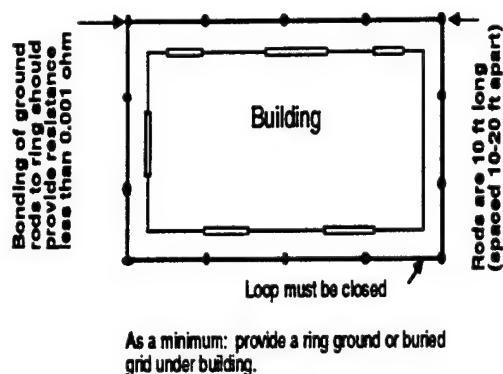


Figure B-2 Earth Electrode Subsystem

It is important that all grounds for the building (i.e., power system ground, signal ground, cable shield grounds, etc.) be bonded to this ring ground. This earth electrode subsystem is often evaluated in terms of its resistance to ground (MIL HDBK 419, 1982 and MIL-STD-188-124A, 1984). This resistance should not exceed 10 ohms. When an earth electrode subsystem is applied to a high-rise building, its primary purpose is to

prevent conducted transients from entering the building. Because of the inductance of long straight wires, and the high frequency content of the transients, it is very important to keep the potential of equipments on the same floor and those interconnected on adjacent floors at the same potential (FIPS PUB-94, 1983). This is the purpose of the signal ground subsystem, described below, which must also be connected to the earth electrode subsystem.

Lightning Protection Subsystem

Extensive guidance is provided in ANSI/NFPA 78 (1986) for the engineering and installation of a lightning protection subsystem. This code is based on a concept of "zone of protection" which recognizes that lightning strikes are developed through the formation of leaders which propagate in increments of about 150 feet, first from a cloud toward earth and finally from earth to step leaders when these reach a striking distance from the earth (See Figure B-3). This zone of protection determines the number and location of air terminals used in the lightning protection subsystem for a particular building construction. The zone of protection replaces an earlier concept of "cone of protection."

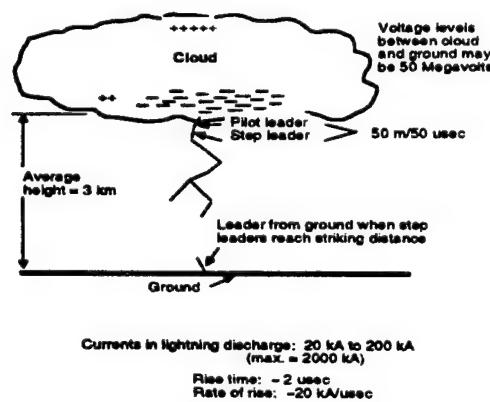


Figure B-3 Formation of Lightning

From a telecommunications perspective, the currents and voltages induced in the lightning grounding subsystem may be very high, and additional care must be exercised to prevent the coupling of these currents or voltages into the sensitive circuitry of the protected terminals and equipments. The rapid rise and decay times of the pulses produced by lightning cause a long conductor, such as those used in connecting the air terminals on a building to the earth electrode subsystem, to act as a low-pass filter with resultant very high transient voltages being generated across such leads (See Figure B-4). Bonding of the lightning ground lead to the structural steel elements of a building and the bonding of these structural steel elements to each other should be a part of the practice, particularly for high-rise structures. This bonding will prevent the buildup of high potentials in the structural elements due to mutual coupling to the lightning protection leads. (Note: Bonding refers to the process by which a low impedance path for the flow of an electric current is established between two metallic objects. Ideally, each of these interconnections should be made so that the mechanical and electrical properties of the

path are determined by the connected members and not by the interconnection junction. Bonding is concerned with those techniques and procedures necessary to achieve a mechanically strong, low impedance interconnection between metal objects and to prevent the path thus established from subsequent deterioration through corrosion or mechanical looseness.) The lightning protection subsystem referred to here is intended to avoid damage to personnel and equipment caused by direct lightning strikes. Additional protection is required to eliminate the transient currents or voltages that may be conducted into the building on cables or other utilities when lightning strikes near the facility. Transient protection of equipment must also be provided to eliminate these non-direct hit phenomena. This transient protection is provided by gas tubes, silicon avalanche suppressors, or similar protection devices discussed below.

Building wiring may require different levels of protection depending on the location and significance of the wiring. Wiring that is used for the interconnection of key departmental communication systems (e.g., computer, video, voice, etc.) among buildings in a campus complex should be carefully shielded and properly grounded to the earth electrode subsystem. Local distribution wiring within a single building may not require lightning protection. Some categories for consideration are the following (GE, _____):

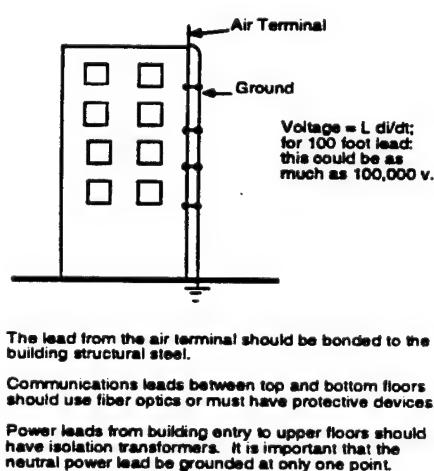


Figure B-4 Lightning Protection Subsystem

Category "A" Wiring--This includes wiring among major building complexes or essential control circuits (the loss of which would have severe economic consequences).

Category "B" Wiring--This is wiring

contained in one major building and does not have connections to points outside of that building.

Category "C" Wiring--This is local distribution within a building. (May not require special lightning protection measures.)

Category "D" Wiring--This wiring extends from a building to an outside exposed area but not to another major building of a complex.

Category "E" Wiring--This wiring runs among buildings but not necessarily major buildings. Damage to this wiring would not have the economic impact of category "A" wiring.

Another area of protection, similar to but in many ways more difficult than lightning protection, is that of High-Altitude Electromagnetic Pulse (HEMP) which would be generated by a nuclear event outside the earth's atmosphere. The HEMP is an electromagnetic radiation phenomenon (Glasstone and Dolan, 1977; EMP Task Force Report, 1984) that results in a plane wave electromagnetic field that covers a very wide frequency spectrum and produces extremely high field strengths. This electromagnetic field is characterized by a very strong magnetic field component and by an overall very high level of incident electric field. (It is imperative that all cable runs in a building be as straight as possible. Also loops in the cable or cross-connect boxes be avoided.) This field is not considered to be dangerous to people (Raiford, 1979) but is potentially devastating to sensitive equipment. It is generally more practical to shield the building or structure in which the equipment is located than to attempt to shield

individual pieces of equipment. (Note: The bonding of the steel structural elements and the rebar elements of a building may provide significant shielding to equipments located inside the building.) Equipment rooms should be located in the center of the building away from exterior walls. Protection of equipment and electronically stored data bases from the above exoatmospheric nuclear hazard is of concern to public safety and public health agencies as well as government and corporate centers which must maintain continuity of service following a possible international terrorist act. Sensitive equipments require shielding, protective devices, and grounding in accordance with recommendations developed by specialists in this field.

The radiated electromagnetic pulses from HEMP will require shielded enclosures (see Annex A for a NATO Specification for such enclosures) to protect the sensitive devices such as integrated circuits, optical detectors, etc. In addition, protective devices will be required on all leads that penetrate this shield. In many cases, entire buildings will require shielding and new building materials are being developed for this application (Huffman, 1988). A plan for evaluating the effectiveness of shielding of this nature and continued inspection and evaluation is required (Ghose, 1984; Thornley, 1988).

Fault Protection Subsystem

This subsystem is a primary concern of the National Electrical Code [ANSI/NFPA No. 70, (1987)]. The purpose of this subsystem is to assure that any fault contact between surfaces that are exposed and the electrical power leads in the building will result in current levels that will open the power circuit fuses or circuit breakers. ["In today's sealed buildings with the entire interior environments totally dependent on effective electrical

usage, the critical role of electrical systems demands not only concern for eliminating fire and shock hazards, but also concern for continuity and reliability of electrical usage as essential to safety of people and property." Quoted from McPartland, (1987).] Two examples of how equipments are interconnected and adequately connected to the building earth electrode subsystem are shown in Figure B-5. This fault protection

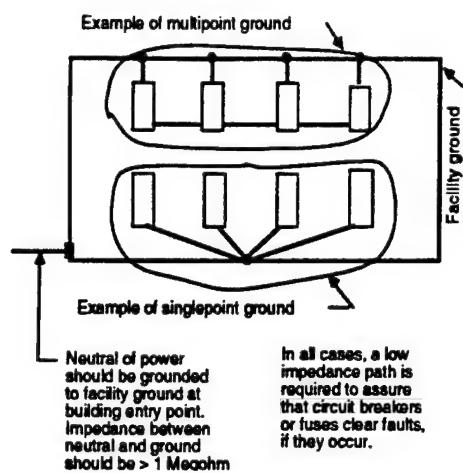


Figure B-5 Fault Protection Subsystem

subsystem must not introduce power currents in the ground leads that serve to provide signal grounding. Note that it is imperative that the neutral of the power sources be connected to the building ground subsystem at the building entry point and that this neutral not be grounded elsewhere in the building.

Signal Ground Subsystem

Signal ground subsystems represent new considerations for commercial buildings (FIPS PUB-94, 1983). When multiple equipments must operate together in a building, the coupling of signals from one set of equipment to another can cause agonizing problems of interference. The single-point ground system shown in Figure B-5 is often

used to provide a signal ground (and eliminate ground loop problems). When the signals contain high frequencies (corresponding to the megahertz radio frequencies) the different lengths of ground bus become different impedances (Terman, 1943) and mutual coupling takes place to cause interference from one cabinet (system) to another. The induced voltages from lightning may cause hazardous potentials to develop between cabinets connected by leads of different length in the single-point grounding system. The multipoint grounding system assures that each cabinet or equipment case is connected to its neighbor via a short ground strap. This will prevent these large voltage transients and provide personnel protection. For systems that operate in the radio frequency region, a signal ground subsystem illustrated in Figure 6 may be required. The size of the grid that makes up this ground plane, to be located under the floor that supports the equipment, will most often be a tradeoff between the desired electrical grounding properties and the physical access requirements through the grid. Dimensions of one-fiftieth of a wavelength of the highest frequency are desirable, but construction practices may dictate dimensions much larger. This grid should remain close to the base of the equipment cabinets to allow short connections to the equipment frames.

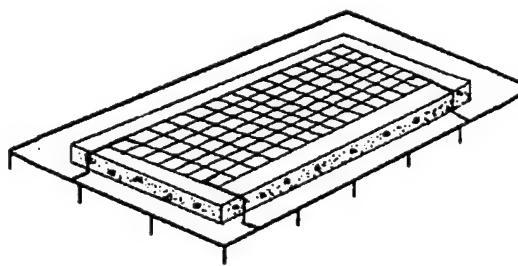


Figure B-6 Signal Ground Subsystem

- 2) Clamping voltage: Arc voltage is 20 volts typical.
- 3) Breakdown voltage: 300 to 500 volts typical.
- 4) Standoff voltage: 75 V dc to 1000 V dc.
- 5) Surge current dissipation: 5000 amperes for 10-by-50 microsecond waveform.
- 6) Lifetime: Varies depending on surge current amplitude, 50 surges of 500 amperes peak current with 10-by-1000 microsecond waveform typical.

SUMMARY

Grounding systems for buildings containing sensitive telecommunication systems require planning at the architectural level and care in the building construction. The extent of the changes in building practices will be dictated by the intended use of the building. Current building codes generally address only the safety aspects of grounding and do not assure that signal grounding can be achieved by these codes. The role of structural steel and rebar used in construction to provide electromagnetic shielding for rooms within the building needs to be considered. Building architects and contractors should not preclude the incorporation of more sophisticated grounding subsystems in buildings where tenants may utilize sensitive electronic/computer equipment or where equipment must respond to emergency needs following a natural or man-made disaster.

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ANNEX A

NATO Specification for Electromagnetic Pulse Shielding

Part 1: Shielded enclosure

- a) The equipment/circuit cards or components and wiring must be placed within a metallic (welded/soldered/bolted) shielded enclosure fabricated of aluminum, copper, or steel with a thickness no less than 0.5 millimeter.
- b) The surge arrestors must be followed by an electrical filter that attenuates the out-of-band signals by 80 dB over the range of 10 kHz to 100 MHz exclusive of the pass band used for equipment operation.
- c) Access panels if necessary must have RFI gaskets.

Part 2: Penetrators

- a) Electrical lines for signal, control, or power that penetrate the shield must be equipped with electrical surge arrestors connected for both common mode and differential mode clamping of transients. The voltage clamp level must be no greater than twice the working voltage of the signal and control line equipment and three times the equipment working voltage level for power lines. Arrestors must clamp in less than 10 nanoseconds.

Part 3: Overall specification

- a) The overall shield and penetrator protection shall attenuate the electromagnetic pulse by 60 dB at 10 kHz rising to 80 dB at 100 kHz at the rate of 20 dB per decade and remaining at 80 dB out to 100 MHz except in the pass band of operating equipment as stated in Part 2 above.

Note: Surge arrestor lead length is somewhat critical and must be kept short. A typical example is about 2.5 cm maximum and a workable implementation has been accomplished by a number of manufacturers. One example is the Siemens Corp., Model B84311 filter which uses a two compartment construction; one for a stop band filter and the second for the surge arrestor, all contained in an RFI-tight compartment which is butted to the shielded enclosures when used with an EMP protected facility/equipment. The concept/principle being that the surge arrestor high frequency currents generated at "turn-on" are confined to the interior surfaces of the RF compartment which is a small RF isolated area.

FOREWORD TO APPENDIX C

This appendix comes from a document submitted to the TIA TR-41.7.2 Working Group (Document number: 90-2-031 AC Power and Environmental Criteria, Telecommunication Sites, submitted by ECOS Electronics Corp., Chris Kleronomous, President). The purpose of this submission was to assist working group members to understand the requirements for grounding and bonding as viewed by this company with many years of experience in the field. It has been the intent of the editor to not include any text that reveals the proprietary recommendations or procedures of the company.

It is not the purpose of this Appendix to create controversy between statements made here and the subject standard. When a difference appears, the Standard produced by TR-41.7.2 will take precedence. This appendix is intended only to clarify or substantiate the requirements of the subject standard. The use of the terms shall and should here are for emphasis only and do not carry the same meaning as that of the subject standard.

The following statement contained in the draft submission is very significant to those experiencing difficulties with sensitive electronic systems installations: "Experience has shown as many as 90% of electronic equipment installations experiencing malfunctions and failures have one or more problems in the wiring and grounding system supplying the equipment. On new installations, connections may be left off or not properly tightened. Reversal of conductors can also occur. Once the installation has been placed in service, vibration can loosen connections. Loads cycling on and off create heating and cooling that can eventually result in poor quality (high impedance) connections. Periodic additions to, and modifications of the distribution system can also result in missing, improper and poor quality connections."

APPENDIX C
AC POWER AND GROUNDING
FOR COMMERCIAL BUILDINGS CONTAINING SENSITIVE ELECTRONIC
SYSTEMS (SES)

BACKGROUND

At the present time numerous Recommended Practices, Installation Guidelines, Military Standards, and National Codes exist regarding the installation of power distribution systems, grounding systems and environmental control systems for Telecommunication sites [or Commercial Buildings meeting the requirements of the Infrastructure Standards described in this report]. Within these [numerous existing] standards also exist conflicts as to exactly what procedure should be followed for the design and installation of the power and grounding systems. The intent of this Appendix is to serve as an extension of the main part of this document. Many technical aspects of grounding and bonding are treated in this document that are not included in the standard, Commercial Building Grounding and Bonding Requirements (to be published as TIA/EIA-607(199X).

INTRODUCTION

Many theories have been promulgated as to how the AC power distribution and grounding system should be installed on sites where Communication/Electronic equipment is to be operated. Several of these theories have been adopted through existing standards, recommended practices and guidelines. Unfortunately, conflicts between these various documents have resulted in field installations that are not uniform, conflict with other standards and potentially represent severe fire and safety hazards to operating personnel, equipment and facilities. These conflicts and non-uniform installations also create an environment that results in performance problems for sensitive electronic

equipment. These problems range from communications failures to actual component degradation and destruction. Most of these equipment malfunctions and failures can be directly attributed to design and installation of the power and grounding system supplying the equipment.

Commercial Codes and Standards

[Although some of these have been referenced and documented in the earlier part of this report, they are repeated here for emphasis.]

National Fire Protection Association (NFPA)

NFPA-70 - National Electrical Code (Current Edition)
NFPA-70B - Electrical Equipment Maintenance (Current Edition)
NFPA-75 - Protection of Electronic Computer/Data processing Equipment (Current Edition)
NFPA-78 - Lightning Protection Code (Current Edition)

Institute of Electrical and Electronic Engineers (IEEE)

IEEE STD. 141 - Recommended Practice for Electrical Power Distribution in Industrial Plants
-IEEE RED BOOK (Current Edition)
IEEE STD. 142 - Recommended Practice for Grounding Industrial and Commercial Power Systems
-IEEE GREEN BOOK (Current Edition)
IEEE STD. 241 - Recommended Practice for Electrical Power Distribution in Commercial Buildings

-IEEE GRAY BOOK (Current Edition)
IEEE STD. 242 - Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

-IEEE BUFF BOOK (Current Edition)
IEEE STD. 399 - Recommended Practice for Power System Analysis

-IEEE BROWN BOOK (Current Edition)
IEEE STD. 446 - Recommended Practice for Emergency and Standby Power for Industrial and Commercial Applications

-IEEE ORANGE BOOK (Current Edition)
IEEE STD. 493 - Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems

-IEEE GOLD BOOK (Current Edition)

PART I - ELECTRICAL POWER REQUIREMENTS

TYPES OF POWER DISTRIBUTION SYSTEMS

Power systems must be designed to provide specific power characteristics required by the telecommunications infrastructure. This involves selection of the primary and auxiliary power sources, secondary substations, UPS or other power conditioning equipment and the low voltage building distribution system. This is required to attain the maximum overall system performance with the most cost effective design. Initiative and engineering judgment must be exercised, considering the assigned mission in each individual case.

In the design of power systems for commercial buildings with emphasis on

telecommunications, consideration must be given to several factors including the following:

- a. Primary power source(s)
- b. Secondary power source(s)
- c. Auxiliary power source(s)
- d. Uninterruptible power source(s)
- e. Location
- f. Reliability
- g. Operability
- h. Maintainability
- i. Flexibility
- j. Expansion
- k. Load Characteristics
- l. Cost effectiveness

INFRASTRUCTURE POWER REQUIREMENTS

For such commercial buildings, the power requirements can be divided into three basic needs: (1) Non-Technical Power, (2) Technical Power, and (3) UPS Power.

Non-Technical Power

This is the power required for such building mechanical and environmental systems as air conditioning and heating, elevators, sump pumps, incinerators and most lighting. The Non-Technical Power system supplies the branch circuit panels in the building for operation of heavy-duty portable equipment such as air compressors, saws, pumps, etc. The Non-Technical Power may also serve as the primary power source for the Uninterruptible Power System (UPS).

Technical Power

This is the power required to supply most of the electronic equipment within the facility. This shall include all of the operationally sensitive equipment except for the critical technical load which requires UPS power (see UPS power). All other technical loads are designated as non-critical. The technical power system may also be the power source for the UPS bypass system.

Uninterruptible Power System (UPS) Power

This is the power required to supply the critical technical loads. The critical technical loads are the equipments or systems for which a momentary power loss will cause a significant operational outage.

These critical loads are synchronized systems, such as alarm systems, time and frequency standards, clock distribution systems, some communications interfaces or terminals, critical computer systems and other designated unique systems or equipments. A solid state UPS consists of a rectifier/charger, batteries, inverter, synchronizing equipment, protective devices, static switches and other accessories. These power systems are characterized by their ability to condition primary or auxiliary power to precise, high quality power, as required by the critical equipment. UPS maintain continuous power during periods of transfer from one power source to another or upon failure of the primary power source. To minimize power loss and to conserve energy, the UPS should be sized to support only the critical load and operate at a high efficiency. Continuity of power during emergency periods of power transfer or power loss is maintained by an energy storage battery. Fifteen minutes of battery backup power is normally sufficient for UPS applications, at which time the auxiliary power plant should be providing the input power or an orderly shutdown of the critical equipment can be accomplished.

ELECTRICAL LOAD CHARACTERISTICS

Linear Loads

Motor, incandescent lighting and heating loads are linear in nature. That is, the load impedance is essentially constant regardless of the applied voltage. For alternating current, the current increases proportionately

as the voltage increases and decreases proportionately as the voltage decreases. This current is in phase with the voltage for a resistive circuit with a power factor (PF) of unity.

The current lags the voltage by some phase angle for a partially inductive circuit with a PF commonly between 0.80 and 0.95, and leads the voltage by some phase angle for the occasional capacitive circuit, but is always proportional to the voltage. For a sinusoidal voltage, the current is also sinusoidal. Figure C-1 represents the voltage/current relationships for linear loads. Until the later 1970's, almost all loads were linear. Non-linear loads were of such small portion as to have little effect on system design and operation. Today's electronic loads, such as computers, UPS equipment, fluorescent lighting and variable-speed motor drives, are mostly non-linear.

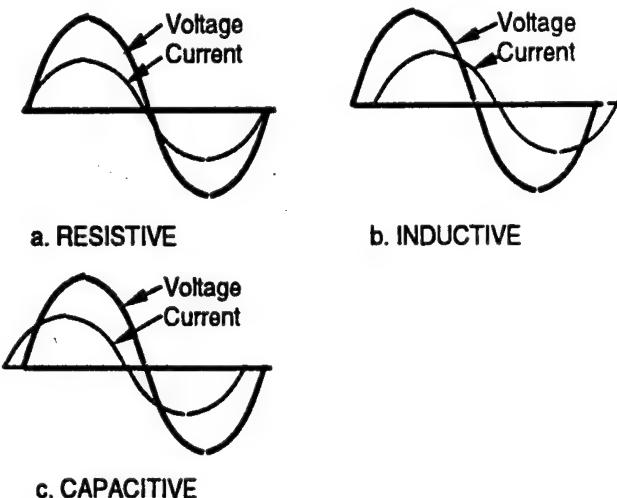


Figure C-1 Linear Loads

Non-linear Loads

These loads are unique in that the load impedance is not constant with respect to the applied voltage. Often, the load current is not continuous. It is switched on for only part of each half cycle, as in a thyristor-controlled

circuit; or pulsed, as in a controlled rectifier circuit, a computer, or power to a UPS. The major effect of non-linear loads is to create considerable harmonic distortion on the power distribution system. Figure C-2 represents the voltage/current relationships for a non-linear load such as a switching power supply.

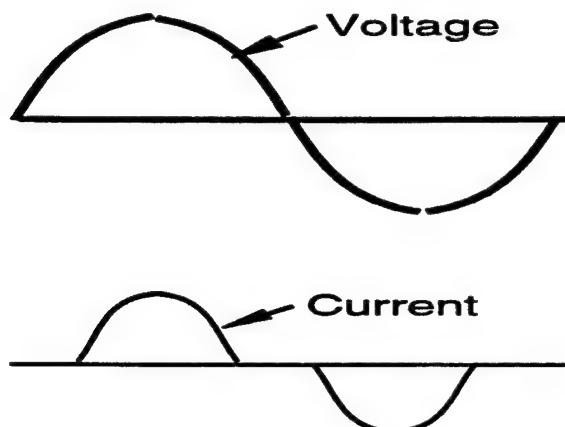


Figure C-2 Non-Linear Loads

Effects of Harmonic Currents

Heating It is common to refer to heating effect as I^2R losses. On a power system with harmonic current flow, the total heating effect is the sum of the fundamental losses and the harmonic losses:

$$\text{Total } I^2R = I^2_{60 \text{ Hz}} \times R_{60 \text{ Hz}} + I^2_{180 \text{ Hz}} \times R_{180 \text{ Hz}} + I^2_{300 \text{ Hz}} \times R_{300 \text{ Hz}} + I^2_{420 \text{ Hz}} \times R_{420 \text{ Hz}} + \text{etc.}$$

Since power system equipment is normally rated based on the 60 Hz losses, the addition of the harmonic losses will require the equipment to be de-rated. The total losses (60 Hz + harmonics) must be kept within the equipment rating.

In sizing equipment such as generators and transformers for systems supplying non-linear loads, a good practice is to keep the

maximum load at 60-70 percent of the equipment rating. Overloading electrical equipment such as transformers will create excessive heating. This accelerates the normal aging process of insulation and will result in premature failure.

Other results of heating caused by harmonic currents include excessive losses and heating in motors and blown capacitor fuses.

Solid State Device Malfunction Harmonics can also affect the performance of solid state devices that are sensitive to zero crossings of the waveform. Phase position of the harmonic current in relation to the fundamental will also have an effect. Figure C-3(a) and C-3(b) illustrate the resultant waveform caused by third harmonic current with different phase relationships.

In Figure C-3(b), the resultant current has more than two zero crossings per cycle. This can disrupt the operation of devices responding to zero crossings.

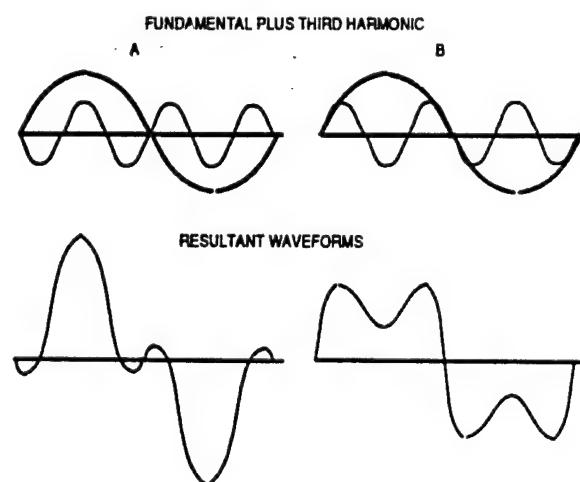


Figure C-3 Voltage Waveform Distortion Caused by Non-Linear Load

Power Factor Correction Capacitors The application of power factor correction

capacitors on a power system can develop resonance conditions when harmonics are present. Both series and parallel resonance or a combination of the two may occur. If the resonant points of either or both types occurs at or near the frequencies of the harmonics, the results can be the flow of excessive harmonic currents and/or the appearance of excessive harmonic overvoltages. This can cause problems such as capacitor bank failures, blown capacitor fuses, insulation failure of cables, etc.

Voltage Waveform Non-linear load currents are non-sinusoidal, and even when the source voltage is a clean sine wave, the non-linear loads can distort that voltage wave, making it non-sinusoidal. Figure C-4 illustrates waveform distortion caused by a non-linear load such as a switching power supply. The amount of waveform distortion is a function of the source impedance. When supplying non-linear loads such as switch-mode power supplies, it is important to keep the source impedance as low as possible to minimize voltage waveform distortion. In selecting power transformers that will supply non-linear loads, it is desirable that the impedance of the transformer be 3-5 percent maximum.

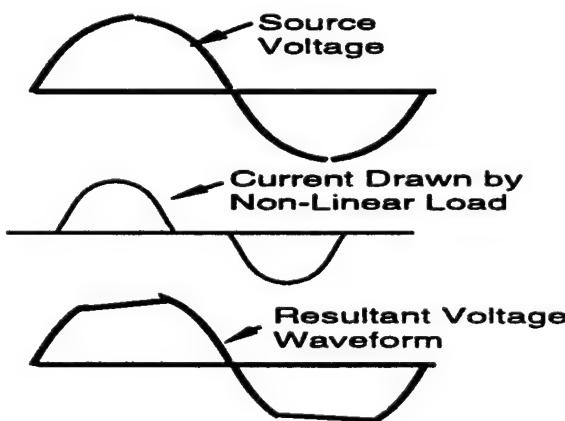


Figure C-4 Voltage Waveform Distortion Caused by Non-Linear Load

Effect of Waveform Distortion "Flattopping" of the sine wave as illustrated in Figure C-4 will have adverse effects on solid state devices operating from the circuit. A typical example is the diode which operates in response to the peak voltage of the sine wave. For user's convenience, it is common to specify the operational settings in terms of the RMS values. When applied to a circuit with a distorted sine wave, the device can malfunction since it is sensing a peak voltage that does not correspond to the RMS value of the waveform.

Additional malfunctions caused by harmonics on the power system include: (a) Errors in measurement equipment; (b) Nuisance tripping of relays and breakers; (c) Interference with motor controllers; and (d) Unstable operation of zero-voltage-crossing firing-circuits, such as SCR's.

Effect on Neutral Conductors On three phase 120/208 volt power systems supplying non-linear loads, it is possible for the neutral current to be substantially larger than the phase currents, as much as 173 percent. This can occur when the phase currents contain high percentages of third and odd multiples of the third harmonic (9, 15, etc.). These zero-sequence phase currents in the neutral add arithmetically rather than cancel each other. It would be practically zero under balanced phase current conditions when the fundamental frequency (60Hz) components of current cancel as ordinarily expected. Figure C-5 illustrates the voltage/current relationships on three phase 120/208 volt power systems supplying non-linear loads.

Sizing of Neutral Conductors Three phase power system neutral conductors need to have an ampacity preferably 175 to 200 percent the normal cross section of the phase conductor to accommodate these high levels of harmonic currents.

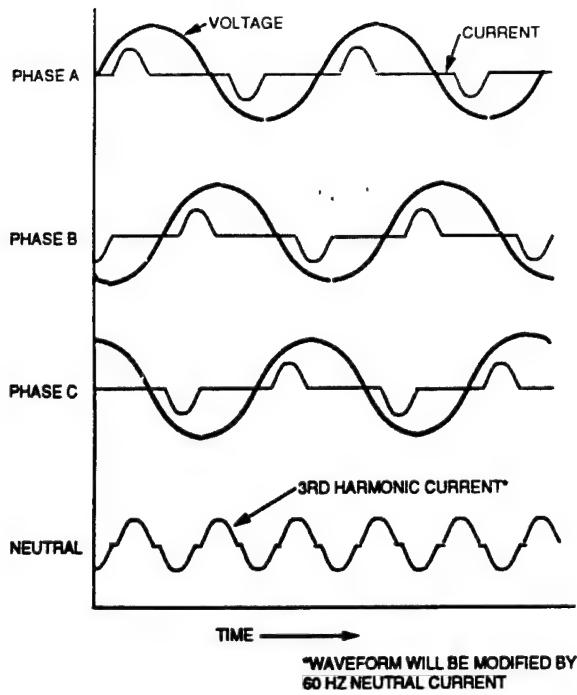


Figure C-5 Third Harmonic Current Phase Relationships

Recommended practice for Telecommunications sites is to size the neutral at 200 percent ampacity of the phase conductors on feeders supplying multiple non-linear loads. Figure C-6 illustrates actual neutral current measurements taken at a



Figure C-6 Three Phase Neutral Current at a Distribution Panel

distribution panel supplying electronic loads. It can be seen that the third harmonic component is actually larger than the fundamental (60 Hz) current.

ELECTRIC SERVICE REQUIREMENTS

Primary Power Source

Dual medium voltage feeders are required to be used to supply the facility. These feeders are best installed underground. In addition, the feeders should be brought to the facility by two different routes to help prevent accidental damage to one from affecting the other. It is desirable to use separate power substation transformers to provide Technical and Non-Technical Power to the Telecommunications site. Each substation transformer may be fed through a transfer switch that is supplied from both medium voltage feeders. It is desirable that primary side overcurrent protection be provided for each transformer. One feeder may be used as the preferred source for the Technical Power transformer and the other feeder may be used as the preferred source for the Non-Technical Power transformer. Each feeder may be sized to provide for total continuous load of both transformers. See Figure C-7 for illustration of the primary feeders and substation transformers.

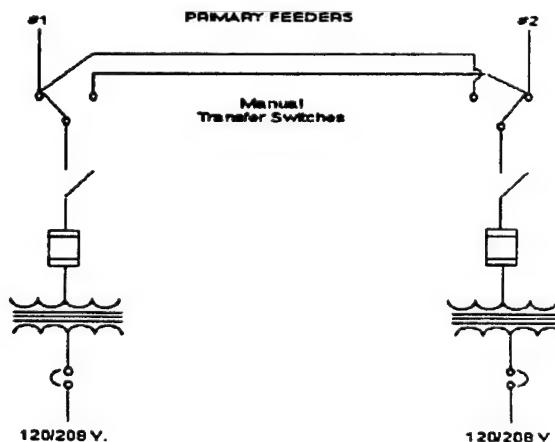


Figure C-7 Primary Feeders and Substation Transformers

Emergency Power Source

These facilities require diesel or other emergency generator systems to provide total backup power to the utility and technical distribution systems. These units must have a generating capacity sufficient to supply the station's design load for an unlimited time with at least a 30 percent reserve, with any one generator off line. This is to ensure that, even with one generator off line for corrective or preventive maintenance, the station shall have sufficient generating capacity to operate in all emergencies. Fuel tank capacity should be sufficient to provide for a minimum of five days of full operation.

Power Source Switching Capability

The primary power and emergency power systems should have the following Utility and Technical bus switching capacity:

1. The ability to transfer the loads from commercial to generator power without power interruption.
2. The ability to transfer the loads from generator to commercial power without power interruption.
3. The ability to parallel the Technical and Utility GENERATOR LOADS together without power interruption.
4. The ability to parallel the Technical and Utility BUS LOADS together without power interruption.
5. The ability to start the Technical and Utility generators automatically or manually from the main bus switching equipments.
6. The ability to disengage the Technical and Utility bus loads automatically upon sensing an under/over voltage/frequency or phase loss or unbalance condition.
7. The bus alarm, monitor, start-up and switching capabilities shall be able to function without primary or emergency power applied to the bus.

8. The ability to monitor ALL building power alarms, switching, loading and distribution functions in one location.

Control Power Power for the control circuits used in the switching operations should be provided through a back-up source to ensure that in the event of a total loss of power to the main switchgear, power is always available to perform control functions such as operation of the transfer switches, starting of the emergency generators and related functions necessary to re-establish power to the facility from the emergency power source. This back-up power source can either be a DC battery supply or single phase UPS depending on the application. The back-up source should be capable of providing control power for a minimum of 15 minutes in the event of loss of the primary power sources.

Availability

The primary power supply, auxiliary power supply and distribution system should be engineered so as to provide 99.99% availability (exclusive of scheduled outages) to the technical and non-technical load busses. See Figure C-8 for a one line diagram of the primary and emergency power feeds.

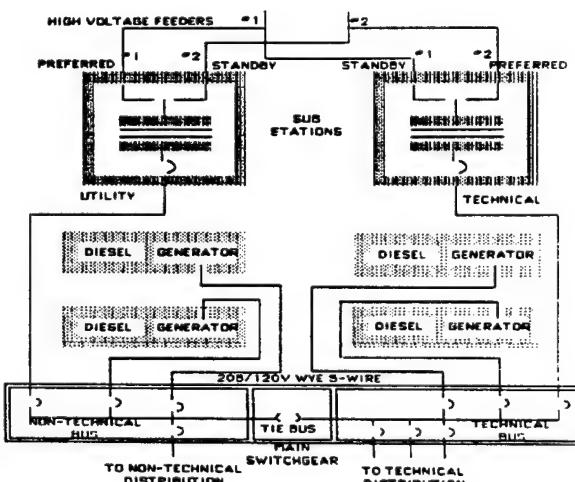


Figure C-8 Primary and Emergency Power Feeds

PART II - FACILITY GROUNDING SYSTEMS

INTRODUCTION

Grounding of a Telecommunication facility [or a commercial building utilizing the infrastructure telecommunications wiring discussed in this report] is one of the most important and least understood aspects of the entire power system. Properly designed grounding systems are necessary to assure safety of personnel, fire and equipment protection, provide lightning protection and create a grounding environment that will result in low levels of electrical noise contributing to the proper operation of sensitive electronic equipment critical to the users' mission(s). All telecommunications and electronic facilities are inherently related to earth by capacitive coupling, accidental contact, and intentional connection. Therefore, grounding must be looked at from a total system viewpoint. The facility grounding system forms a direct path of known low impedance between earth and the various power, communications, and other equipments that effectively extends an approximation of ground reference throughout the facility. The facility grounding system is composed of the following components:

- a. Earth Electrode System
- b. Equipment Grounding System

In addition, the following systems play a role in the overall protection and performance of the facility:

- c. Lightning Protection System
- d. Signal Reference System

To serve their intended purpose, the Lightning Protection System must be effectively connected to the Earth Electrode System and the Signal Reference System must be effectively connected to earth through the Equipment Grounding System to reduce levels of electrical noise.

GROUNDING DEFINITIONS

What is a Ground?

Grounding is one of the most important and least understood aspects of the entire electrical system. When the word "GROUND" is mentioned, people normally think of a connection to a water pipe or a ground rod. The National Electrical Code defines "GROUND" and "GROUNDED" as follows:

"GROUND" "A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and earth, or some conducting body that serves in place of the earth."

"GROUNDED" "Connected to earth or to some conducting body that serves in place of the earth."

Note that the phrase "...or some conducting body that serves in place of the earth..." is included in the National Electrical Code definition for both "GROUND" and "GROUNDED". This means a "ground" can be established without a connection to earth as long as connection is made to "some conducting body that serves in place of the earth".

To clearly understand the purpose and function of grounding electrical systems and equipments, the single subject of grounding must be subdivided into two categories; EARTH GROUNDING and EQUIPMENT GROUNDING. These two categories are often interchanged and the resultant misapplication of earth and equipment grounding practices can lead to a system that is expensive, inefficient and even unsafe. The various components and

definitions that make up the equipment and earth grounding system are listed in Table C-1 and illustrated in Figure C-9.

Table C-1 Equipment and Earth Grounding System

GROUNDED CONDUCTOR (NEUTRAL)

A system or circuit conductor that is intentionally grounded.

EQUIPMENT GROUNDING CONDUCTOR (SAFETY GROUND)

A system used to connect the non-current carrying metal parts of equipment, raceways and other enclosures to the system grounded conductor and/or the grounding electrode conductor at the service equipment or at the source of a separately derived system.

MAIN BONDING JUMPER

The connection between the grounded conductor (Neutral) and the equipment grounding conductor (Safety Ground) at the service entrance equipment.

GROUNDING ELECTRODE CONDUCTOR (EARTHING CONDUCTOR)

The conductor used to connect the grounding electrode to the equipment grounding conductor (Safety Ground) and/or to the grounded conductor (Neutral at the service equipment) or at the source of separately derived system.

GROUNDING ELECTRODE (EARTHING ELECTRODE)

A current carrying (metallic) item such as a rod, plate, pipe, etc. imbedded in the earth.

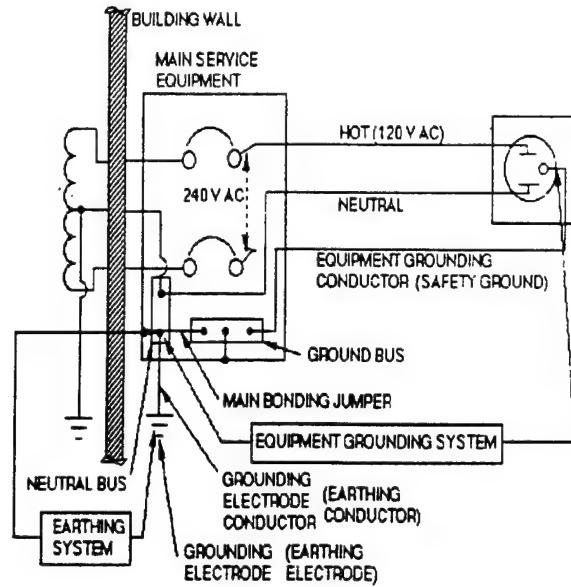


Figure C-9 Grounding System Components

Equipment Grounding Conductor (Safety Ground) The conductor used to connect the non-current carrying metal parts of equipment, raceways and other enclosures to the system grounded conductor and/or the grounding electrode conductor at the service equipment or at the source of a separately derived system.

Main Bonding Jumper The connection between the grounded conductor (Neutral) and the equipment grounding conductor (Safety Ground) at the service entrance equipment.

Grounding Electrode Conductor (Earthing Conductor) The conductor used to connect the grounding electrode to the equipment grounding conductor (Safety Ground) and/or to the grounded conductor (Neutral) at the service equipment or at the source of separately derived system.

Grounding Electrode (Earthing Electrode) A current carrying (metallic) item such as a rod, plate, pipe, etc. imbedded in the earth.

EARTH GROUNDING

The basic purpose of the Earth Grounding System is to protect the electrical system and equipment from super-imposed voltages caused by lightning and accidental contact with higher voltage systems. The earth ground connection is also required to prevent the build-up of static charges on equipment and materials.

An additional purpose of the earth ground is to establish a "zero voltage" reference point for the system. This purpose is the one that is important to ensure proper performance of sensitive electronic and communication equipment critical to the station mission.

Earth Resistance Components

When an Earth Electrode System is established, the resistance is made up of three components:

- Resistance of the electrodes and connections to the electrodes,
- the contact resistance of the electrodes to the adjacent earth, and
- the resistance of the body of earth surrounding the electrodes.

Studies have shown that the majority of the resistance is comprised of the body of earth surrounding the electrode. Figure C-10 illustrates this condition for a single ground rod. The body of earth can be broken into

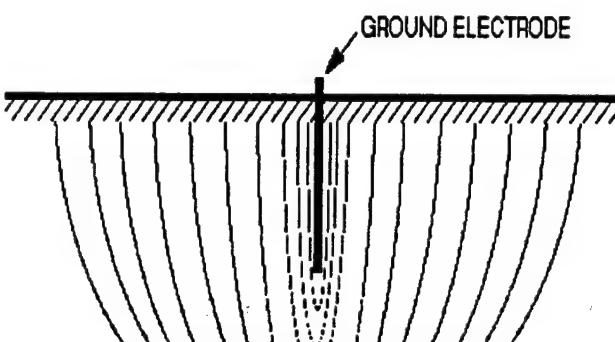


Figure C-10 Resistance of Earth Surrounding Electrode

several concentric "shells" of earth surrounding the GROUNDING ELECTRODE. The "shells" close to the electrode have a small cross sectional area and exhibit a relatively high resistance. As more "shells" are added, each succeeding "shell" has a larger cross sectional area and a lower resistance. Therefore, a point is reached where adding additional "shells" will not affect the resistance of the electrode. It is at this point where the "effective" body of earth that makes up the resistance of the electrode is established.

The resistivity of the soil into which the electrode is driven is the key factor that determines what the resistance of the electrode will be. Soil resistivity varies widely and is also affected by moisture content and temperature. IEEE Standard 142, "Recommended Practice for Grounding of Industrial and Commercial Power Systems" (Green Book), contains the following Tables (C-2 through C-4) showing these effects:

Table C-2 Soil Resistivity

Soil	Resistivity of Soils and Resistances of Single Rods					
	Resistivity Ohm-cm			Resistance of 5/8" X 10' Rod (Ohms)		
	Avg	Min	Max	Avg	Min	Max
Fills, ashes, cinders, brine, waste, salt						
marsh	2370	590	7000	8	2	23
Clay, shale, gumbo, loam	4060	340	16300	13	1.1	54
Same, with added sand and gravel	15800	1020	135000	5	24	447
Gravel, sand, stones, with little clay or loam	94000	59000	458000	311	195	1516

Reducing Earth Electrode Resistance

When a high resistance electrode is encountered, there are three means to lower

Table C-3 Moisture Content

Effect of Moisture Content on Soil Resistivity		
Moisture Content (% by weight)	Resistivity (Ohm-cm)	
	Top Soil	Sandy Loam
0	$>1000 \times 10^6$	$>1000 \times 10^6$
2.5	250000	150000
5	165000	43000
10	53000	18500
15	19000	10500
20	12000	6300
30	6400	4200

Table C-4 Temperature

Effect of Temperature on Soil resistivity (Sandy loam, 15.2% moisture)		
Temperature (Deg. C)	(Deg.F)	Resistivity (Ohm-cm)
20	68	7200
10	50	9900
0 (water)	32	13800
0 (ice)	32	30000
-5	23	79000
-15	14	330000

its resistance to the desired level, namely: (a) driving the electrode deeper; (b) using multiple electrodes connected together; and/or (c) soil treatment.

Driving Deep Electrodes Doubling the depth of an electrode will reduce its resistance by approximately 40 per cent. Recommended depth for earth electrodes on commercial sites, where sensitive electronic systems are to be used, is 20 feet. However, in many areas it may not be possible to drive the electrode to the desired depth due to bedrock or other soil conditions.

Figure C-11 illustrates the effect of increasing the depth of an earth electrode. For this type

of soil, moisture and temperature conditions, a one inch diameter electrode driven ten feet deep has a resistance of 30 ohms. If the depth of the electrode is increased to twenty feet, the resistance decreases to about 18 ohms, or a reduction of about 40 per cent. Note that there is little difference between the resistance of a 1/2-inch electrode and a one-inch electrode. This is due to the fact that the size of the electrode has little effect on the resistance of the electrode.

Multiple Electrodes Where deep driving an electrode is not practical, multiple electrodes can be driven and connected in parallel to lower the resistance. Multiple electrodes tend to follow the law of parallel resistors, however, to reach the 50 per cent reduction in resistance, the electrodes would have to be spaced a distance approximately ten to twenty times their driven depth which is impractical. By spacing the electrodes at a distance twice their driven depth, about a 40 per cent reduction in the resistance is achieved each time the number of electrodes is doubled.

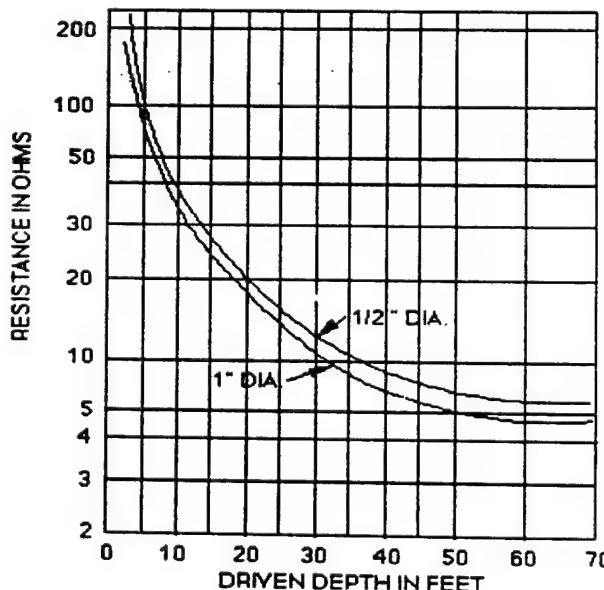


Figure C-11 Effect of Depth on Electrode Resistance

Figure C-12 illustrates the reduction in electrode resistance that can be expected with various spacings. This chart can be used to determine how many electrodes will be required to achieve the desired resistance once the resistance of the initial electrode is known. Recommended practice when installing a perimeter ground grid in Telecommunication sites is to install 20 foot ground rods spaced 40 feet apart. This depth and spacing maximizes the benefits of a multiple-rod grid.

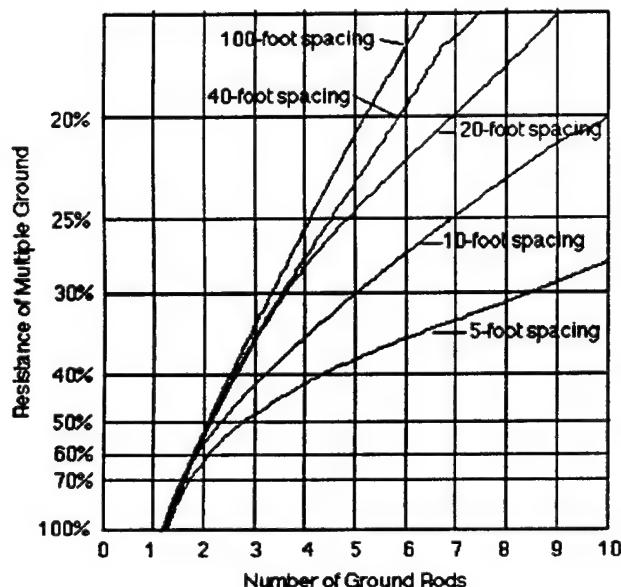


Figure C-12 Effect of Spacing for Multiple Electrodes

Soil Treatment Where deep driving or multiple electrodes cannot be used, the soil can be chemically treated to reduce the resistance. A trench about three foot in diameter is dug around the electrode and filled with a salt such as magnesium sulfate, copper sulfate or rock salt. Figure C-13 illustrates this method of reducing electrode resistance. NOTE: This method shall only be used after all other methods have been exhausted. Soil treatment can possibly contaminate the local water supply. Obtain approval from the appropriate environmental authorities before proceeding with soil treatment of electrodes.

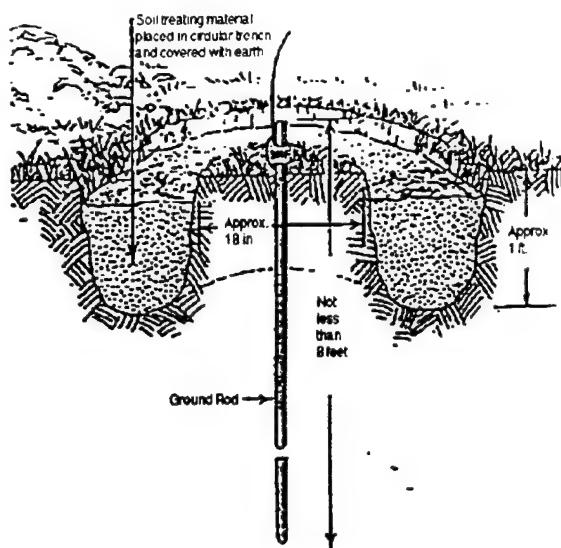


Figure C-13 Trench Method of Soil Treatment

One advantage of the soil treatment method to reduce electrode resistance is that seasonal variations will also be minimized as illustrated in Figure C-14. One disadvantage is that the salt will gradually dissipate and have to be replaced as illustrated in Figure C-15.

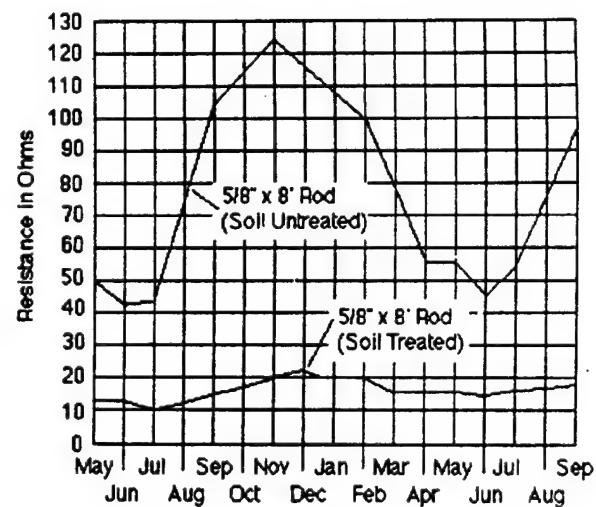


Figure C-14 Reduction of Seasonal Variations by Soil Treatment

A second disadvantage of the soil treatment method is that corrosion of the electrodes

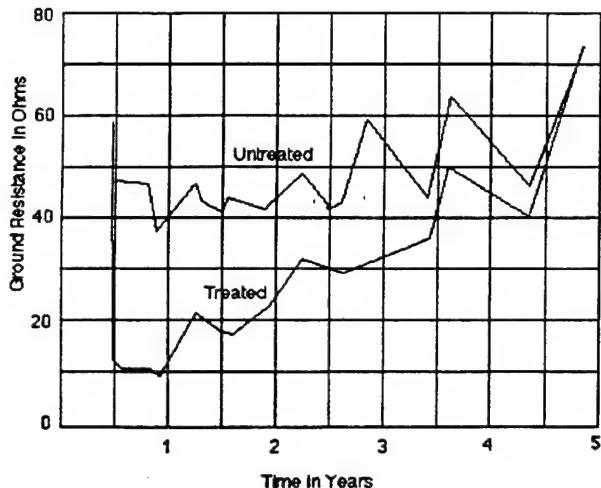


Figure C-15 Dissipation of Soil Treatment with Time

could occur under certain soil and moisture conditions.

EQUIPMENT GROUNDING

In contrast to earthing, the purpose of equipment grounding is to assure that all the exposed, non-current carrying, conductive surfaces such as equipment enclosures, conduits, raceways, ducts, etc. are effectively interconnected to earth. The objectives achieved by effective equipment grounding are basically threefold:

- To minimize to the greatest extent possible the appearance of any voltages on equipment enclosures. This will provide protection from serious shock and/or electrocution to personnel in contact with the enclosure.
- To provide an intentional path of ample current carrying capacity and low impedance that will carry sufficient fault current to insure rapid operation of the circuit overcurrent protective device under ground fault conditions.
- To establish and maintain a "ZERO-VOLTAGE" reference point

at the location of sensitive electronic equipments such as computer systems, telecommunications systems, etc. that will contribute to proper operation of this sensitive electronic equipment critical to successful mission accomplishment.

Effective Grounding

To accomplish the three objectives outlined above, the equipment grounding system must be effective. Effective Grounding is defined by the National Electrical Code, Article 250-51 as follows:

"EFFECTIVE GROUNDING PATH.

The path to ground from circuits, equipment and conductor enclosures SHALL:

- be permanent and continuous;
- have capacity to conduct safely any fault current likely to be imposed on it;
- have sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit; and
- The earth SHALL NOT be used as the sole equipment grounding conductor."

It becomes clear that if the objectives are to be achieved, the equipment grounding system must meet all four requirements as outlined in Article 250-51 (listed above) and that if all four of the requirements are not met, then effective grounding has not been achieved and the system is unsafe.

LIGHTNING PROTECTION SYSTEM

The lightning protection system provides a nondestructive path to ground for lightning energy contacting or induced in facility

structures. To effectively protect a building, mast, tower, or similar self-supporting objects from lightning damage, an air terminal of adequate mechanical strength and electrical conductivity to withstand the stroke impact must be provided. An air terminal will intercept the discharge to keep it from penetrating any nonconductive outer coverings of the structure, or prevent it from passing through devices likely to be damaged or destroyed. A low impedance path from the air terminal to earth must also be provided. These requirements are met by either (1) an integral system of air terminals, roof conductors, and down conductors securely interconnected to provide the shortest practicable path to earth; or (2) a separately mounted shielding system, such as a metal mast or wires (which act as air terminals) and down conductors to the earth electrode system. The earth electrode system to which the lightning protection is connected SHALL be the same earth electrode system used for the facility to prevent potential differences from developing between the grounding systems under lightning surge conditions.

Lightning Protection Principles

A structure, for lightning protection purposes, is defined as a building mast, tower, or similar self-supporting object other than power lines, power stations, and substations.

To provide minimum protection for structures against direct lightning strikes, four requirements must be fulfilled:

- a. an air terminal must be provided to intentionally attract the leader stroke;
- b. a path must be established that connects this terminal to earth with such a low impedance that the discharge follows it in preference to any other;
- c. a low resistance connection must be made with the earth electrode system; and

- d. a low impedance interface must be established between the earth electrode system and earth.

These conditions are met when a lightning discharge is permitted to enter or leave the earth while passing through only conducting parts of a structure. The conditions can be satisfied by one of two methods, each having specific applications. These methods are: (a) the installation of an integral protection system consisting of air terminals interconnected with roof and down conductors to form the shortest practicable distance to ground or (b) the installation of a separately mounted protection system of one of two types, namely: (1) a mast type consisting of a metal pole which acts as both air terminals and down conductor (a nonconductive pole may be used if provided with metal air terminals and down conductors connected to an earth ground) or (2) two or more poles supporting overhead ground wire connected to an earth electrode system with down leads.

Fundamentally, it is preferable to "dump" as much lightning stroke current directly to earth as is economically feasible. This reduces the proportion of the stroke current seeking remote earth over connecting lines and thus simplifies the task of protecting communications facilities. It is therefore important to provide as many direct, low impedance paths as possible to the earth electrode system.

Facility Lightning Protection

It is estimated that, worldwide, there are an average of 2,000 thunderstorms in progress at any one moment. Isoceraunic maps, such as that shown in Figure C-16, have been developed by the US Weather Bureau to show the frequency of occurrence of thunderstorms.

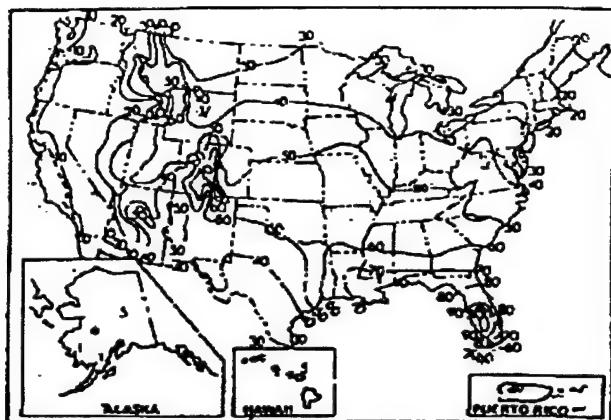


Figure C-16 Isoceraunic Map of the United States Showing Mean Annual Number of Days with Thunderstorms

Similar charts are available that show the average number of thunderstorms throughout the world for each month. These data can be used to determine how comprehensive a lightning protection system must be to provide the degree of protection required for a given area or site.

Zones of Protection

The ability of tall structures or objects to attract lightning to themselves serves to protect shorter objects and structures. In effect, a taller object establishes a protected zone around it. Within this protected zone, other structures and objects are protected against direct lightning strokes. As the height of surrounding objects increases, the degree of protection provided to these shorter objects increases.

Likewise, as the separation between tall and short structures increases, the protection afforded by the tall structure decreases. The protected space surrounding a lightning conductor is called the cone (or zone) of protection. The cone of protection provided by a grounded vertical metal rod or mast and that provided by a grounded horizontal overhead wire are shown in Figure C-17.

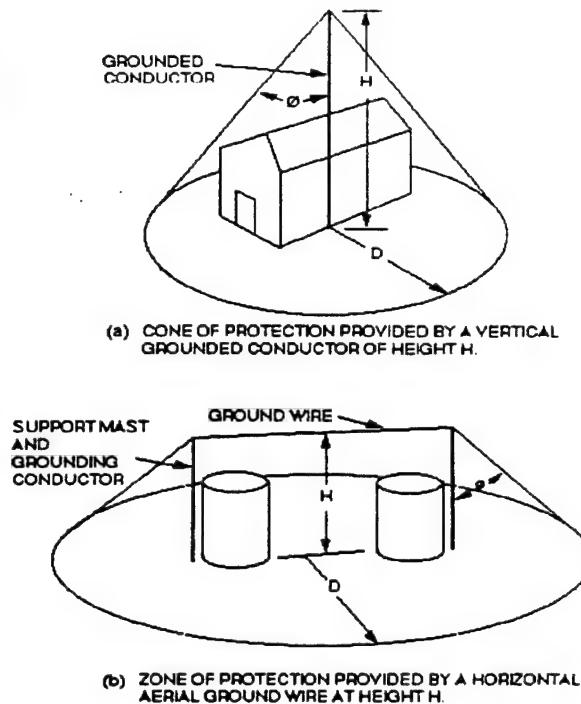
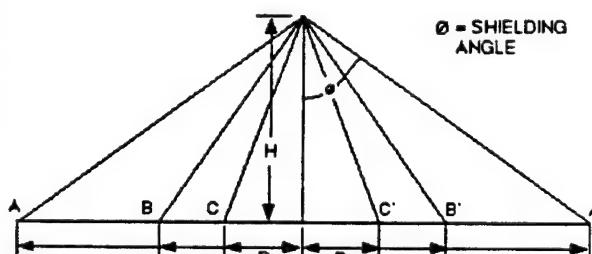


Figure C-17 Cones of Protection

For both cases, the cone of protection is expressed as the ratio of the horizontal protected distance, D , to the height, H , of the mast or wire. Some commonly recommended cones of protection and associated shielding angles are shown in Figure C-18. Generally, a 2:1 ratio (zone A, Fig. C-18) can be considered adequate for ordinary cases where



ZONE	D/H	θ	REFERENCE	RECOMMENDED FOR
AOA	2/1	63°	NFPA 78	ORDINARY CASES
BOB	1/1	45°	NFPA 78 BRITISH CODE	IMPORTANT CASES ORDINARY STRUCTURES
COC	0.58/1	30°	BRITISH CODE	CRITICAL STRUCTURES

Figure C-18 Protection Ratios

the building or structure is not considered essential to the mission. A 1:1 ratio (zone B) shall be used to determine the protection required for mission-essential buildings and structures (important cases). A 0.58:1 ratio (zone C) is only required in critical cases - such as the storage of fuel or explosives - or when designated critical by a competent authority.

Integral Protection System

When designing and installing an integral system of protection, the following steps need to be performed:

- a. Erect air terminals on the points of highest elevation and on other exposed areas to intercept the stroke before it has an opportunity to damage the structure or equipments or components mounted thereon. The terminal points must be placed high enough above the structure to eliminate the danger of fire from the arc.
- b. Install roof and down conductors so that they offer the least possible impedance to the passage of stroke currents between the air terminals and the earth. The most direct path is the best. Avoid sharp bends in conductors that will increase impedance. Keep bend radii a minimum of 8 to 12 inches.
- c. Distribute ground connections symmetrically about the circumference of the structure rather than grouping to one side.
- d. Interconnect all metal objects close to the discharge path to prevent side flashes.

- c. Make certain that the mechanical construction of the air terminal system is strong and that the materials used offer high resistance to corrosion.

Separately Mounted Protection Systems

Mast Type No part of the structure being protected should extend outside the protected zone as calculated by the procedure illustrated by Figure C-18.

Where it is impractical to provide a common mast to provide protection for an entire structure, additional masts should be provided.

If the pole is made of a nonconducting material, provide an air terminal extending not less than 0.6 meters (2 feet) nor more than 0.9 meters (3 feet) above the top of the pole. Connect the base of the mast (if metal) or the down conductors to the earth electrode system of the protected structure with at least a No. 6 AWG copper conductor or equivalent.

Verification of Protection

After the installation has been completed, the Cognizant Authority shall verify that all structure parts fall within the desired cone of protection by determining the distance-to-height ratio from the installation drawing.

Large structures with flat or gently sloping roofs that do not fall within the protection of an antenna tower do not lend themselves to the straightforward application of the shielding angles given in Figure C-18. Experience has shown that very tall air terminals are not required; multiple air terminals 10 to 36 inches high, spaced at large distance-to-height ratios, will provide effective protection.

EARTH ELECTRODE SYSTEM

The earth electrode system consists of a network of earth electrode rods, plates, mats, or grids and their interconnecting conductors. The extensions into the building are used as the principal ground point for connection to equipment ground systems serving the facility. Ground potential is established by electrodes in the earth at the site or installation.

Design Considerations

The earth electrode system establishes the electrical connection between the facility and earth. This connection is necessary for lightning protection and the minimization of noise between interconnected facilities. The system should be tailored to reflect the characteristics of the site and the requirements of the facility. It must be properly installed and steps must be taken to assure that it continues to provide a low resistance connection throughout the life of the structure.

The value of 10 ohms or less earth electrode resistance recommended in MIL-HDBK-419A and MIL-STD-188-124A represents a carefully considered compromise between overall lightning protection requirements and the estimated relative cost of achieving the resistance in typical situations. In locations characterized by high soil resistivities, to achieve 10 ohms could be very expensive. In such locations, examine all elements of the site, consider the requirements of the facility, and then choose the best compromise based on soil conditions, relative costs, etc.

Configuration

The basic earth electrode system configuration shall consist of 20 foot driven ground rods uniformly spaced a distance of

twice the rod length around the facility and placed approximately 0.6m (2 feet) to 1.8m (6 feet) outside the drip line of structures. The rods shall be interconnected with a minimum #1/0 AWG (American Wire Gage) bare copper cable buried at least .9m (3 feet) below grade level. Larger size cables as well as greater burial depths shall be specified where earth and atmosphere considerations so dictate. The interconnecting cable shall close on itself to form a complete loop with the ends brazed or welded together. See Figure C-19 for a typical installation.

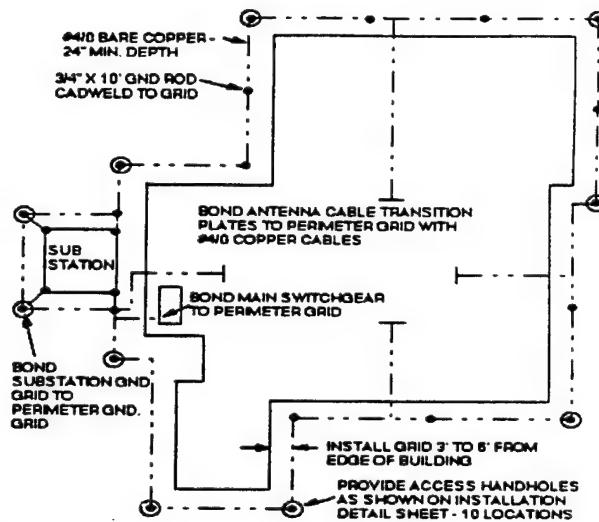


Figure C-19 Perimeter Ground Grid Installation

Access to Grid

Ground wells shall be employed to provide access points at each ground rod installed as part of the grid. Acceptable bolted type connectors should be utilized to bond the cable to the ground rod to permit periodic testing of the individual ground rods. See Figure C-13 for illustration of the ground wells. Coverage of the earth electrode system by asphalt, concrete, etc. shall be kept to a minimum in an effort to maintain the effectiveness of the system. Refer to MIL-HDBK-419 for additional information.

Ground Rods

Ground rods shall be copper-clad steel, a minimum of 6m (20 feet) in length, spaced apart a distance of twice the rod length, and shall not be less than 1.9cm (3/4 inch) in thickness. The thickness of the copper jacket shall not be less than 0.3 mm (0.012 inch).

Connecting Risers

Provisions shall be made for bonding the lightning down conductors, the connecting cables required by the signal reference and fault protection systems, and the antenna cable entrance plates to the risers of the earth electrode system. Ground rods shall be installed at all points where lightning down conductors are to be connected to the earth electrode system. See Figure C-20 for illustration.

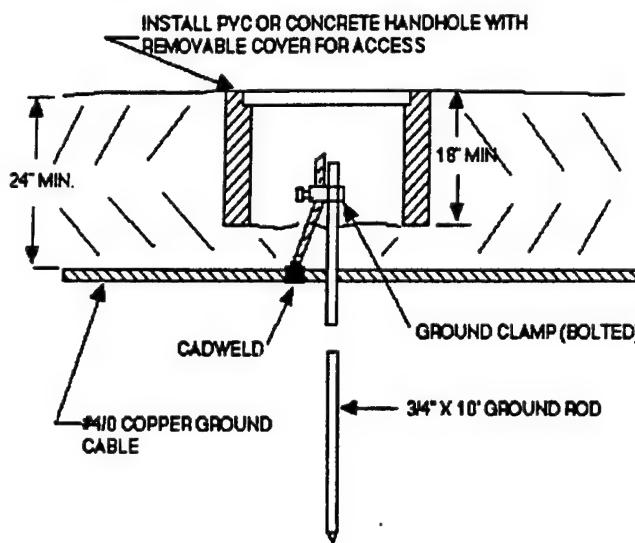


Figure C-20 Ground Well Installation

Other Underground Metals

Underground metallic pipes entering the facility shall be bonded to the earth electrode system and where available, to an entrance plate with a minimum length of bare #1/0 AWG copper cable whenever such connections are acceptable to both the serving suppliers and the authority having jurisdiction. The bond cable shall be welded or brazed to the earth

electrode system. Adequate corrosion preventive measures shall be taken. Structural pilings, tanks, and other large underground metallic masses near the periphery of the structure shall be bonded in a like manner to the earth electrode system. Caution shall be used when using clamps to ground metallic gas pipes.

Resistance to Earth

The resistance to earth of the earth electrode system shall not exceed 10 ohms. Where 10 ohms minimum resistance is not obtained with the basic electrode configuration due to high soil resistivity, rock formations, or other terrain features, alternate methods for reducing the resistance to earth shall be considered. Contact the Cognizant Authority for recommendations on reducing the resistance of the earth electrode system. For additional information on alternate methods as well as test procedures, see MIL-HDBK-419. [Note: The NEC does not require 10 ohms minimum resistance. If a single ground rod is driven and a resistance greater than 25 ohms is obtained, a second ground rod should be driven and connected to the first. --Editor.]

EQUIPMENT GROUNDING SYSTEM

The equipment fault protective system ensures that personnel are protected from shock hazard and equipment is protected from damage or destruction resulting from faults that may develop in the electrical system.

Deliberately engineered grounding conductors are provided throughout the AC distribution system to have sufficient capacity and low impedance so that overcurrent devices (fuses and circuit breakers) can operate promptly when a ground fault occurs. The equipment grounding conductors shall be installed in the same conduit or raceway as

the supply conductors throughout the distribution system. This is required by the National Electrical Code (NEC), Article 250-51 and MIL-STD-188-124A to assure that a low impedance path for fault currents is maintained. The equipment grounding conductors shall also be bonded into the signal reference system at the ground bus in each supply panel in the room. The purpose of each segment of the Equipment Grounding System is provided in Table C-5.

Table C-5 Purpose of Equipment Grounding System

GROUNDED CONDUCTOR (NEUTRAL)

- (a) To permit utilization of power at line to neutral voltage.
- (b) To provide a low impedance path for load and fault currents to return to the source transformer neutral.

EQUIPMENT GROUNDING CONDUCTOR (SAFETY GROUND)

- (a) To maintain zero volts on equipment enclosures during normal operation.
- (b) To provide a low impedance path of ample capacity to carry fault current when a phase-to-ground fault occurs.

MAIN BONDING JUMPER

- (a) To provide a low impedance path of ample capacity from the equipment grounding conductor to the grounded conductor (Neutral).

Types of Faults

Three types of high current faults may occur on an electrical system, namely: (a) phase to phase; (b) phase to neutral; or (3) phase to ground.

A phase to phase or phase to neutral fault will be readily cleared by the overcurrent device, providing the device has been properly selected and coordinated into the system.

It is beyond the scope of this document to discuss coordination of overcurrent devices. Reference material on this subject can be found in IEEE Standard 242, "Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems" (IEEE Buff Book).

An EQUIPMENT GROUNDING CONDUCTOR (SAFETY GROUND) is required to: (a) maintain zero volts on equipment enclosures during normal operation; and (b) provide a low impedance path of ample capacity to carry fault current when a phase-to-ground fault occurs.

The MAIN BONDING JUMPER provides a low impedance path of ample capacity from the equipment grounding conductor to the grounded conductor (Neutral). Experience has proved that the greatest majority of faults that occur on electrical systems are phase to ground faults. It is of utmost importance to remove a ground fault as soon as possible from both a personnel safety and equipment protection point of view.

When a ground fault occurs, the following segments of the grounding system shall be required to carry practically the entire fault current: (a) the Equipment Grounding Conductor (Safety Ground); (b) the Main Bonding Jumper; and (c) the Grounded Conductor (Neutral) from the service equipment to the transformer neutral point.

The following segments of the grounding system shall not be required to carry the fault current: (a) the Grounding Electrode Conductor (Earthing Conductor); and (b) the Grounding Electrode (Earthing Electrode).

Effective grounding must be accomplished to assure rapid operation of the overcurrent device when a ground fault occurs. When there is accidental contact between an

energized electrical conductor and the metallic frame or cabinet, the frame or cabinet tends to become energized to the same potential that exists on the energized conductor.

To oppose this tendency, the equipment grounding system must present a low impedance path from the stricken frame or cabinet to the zero potential reference ground junction at the service equipment or secondary of a separately derived system.

Should the overcurrent device operate slowly or not at all, the results can be any combination of the following: (a) electrocution of personnel; (b) fire; and/or (c) destruction of equipment.

Ground Fault Protection

Protection against ground faults can be divided into two categories: (1) personnel protection; and (2) equipment protection.

By assuring that a high degree of personnel protection is provided from ground faults, a high degree of fire and equipment protection will also be achieved. Personnel protection can be provided by two means: (1) effective grounding of circuits and equipments; and (b) the use of Ground Fault Circuit Interrupters on circuits.

Effective Grounding Figure C-21 illustrates a typical 120VAC circuit operating under normal conditions. The Earth Electrode System establishes a zero voltage reference at the Main Panel while the Equipment Grounding System extends this zero voltage reference from the Main Panel to the equipment metallic enclosure (cabinet).

Operating personnel in contact with the cabinet and any other grounded (zero voltage) surface will not be exposed to an electrical

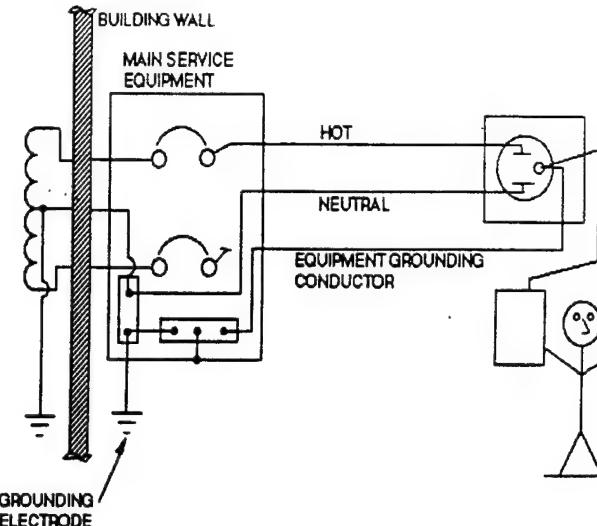


Figure C-21 120VAC Circuit Under Normal Conditions

shock since there is no potential difference across the operator.

Under normal operating conditions, the load current flows on the Hot and Neutral conductors and no current flows on the Equipment Grounding Conductor. The zero voltage reference established by the Grounding Electrode at the Main Service Equipment is extended by the Equipment Grounding Conductor to the equipment enclosure. By maintaining zero volts on the equipment enclosure, protection against electrical shock to the operator is achieved.

When a ground fault occurs, the Equipment Grounding Conductor becomes the return path for fault current to flow back to the source. A low impedance path is essential so that sufficient fault current is developed to cause a rapid operation of the circuit breaker. The equipment enclosure will have a potential to ground resulting in a current flow through the operator's body until the circuit breaker trips and opens the circuit.

Note that the grounding electrode (connection to earth) plays no part in achieving

overcurrent protection by tripping the circuit breaker. Figure C-22 illustrates the same 120VAC circuit under a ground fault condition. To establish a "worst case" condition, the phase conductor impedance is 0 ohms and all impedance is contained in the equipment grounding conductor. This condition establishes the maximum shock hazard voltage that will be exposed across the operator (120VAC). Any impedance in the phase conductor would create a voltage drop and not result in a "worst case" shock exposure condition to the operator.

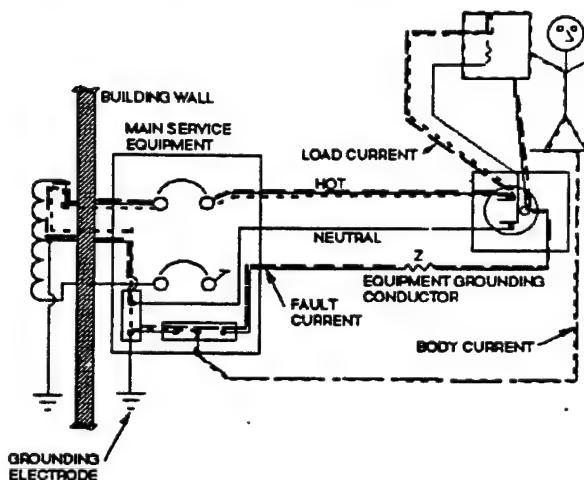


Figure C-22 120VAC Circuit Under Ground Fault Conditions

Extensive research has been conducted on the effects of electrical current flowing in the human body. As a result of this research, it has been determined that the following formula defines the heart fibrillation threshold for a 68kg (150lb.) individual.

$$I^2t=0.027$$

Reference IEEE Conference Record Paper #CH1460-5/79/0000-49, "A Practical Approach to Establish Effective Grounding for Personnel Protection.

Table C-6 illustrates the effects of various levels of 60Hz currents on a 68kg (150lb) human being.

Table C-6 Shock Currents and Effects

CURRENT	EFFECT
<1 ma	Imperceptible
1 ma	Perception Threshold
1-3 ma	Mild Sensation
3-9 ma	Painful Sensation
10 ma	Paralysis threshold of arms. Cannot release hand grip. May progress to higher current and be fatal.
30 ma	Respiratory paralysis. Possibly fatal if current is not interrupted.
60 ma	Heart Fibrillation threshold 0.5 percent. Usually fatal.

According to UL, ANSI and other standards, the worst case body impedance under wet skin conditions is 1500 ohms. The body current for an individual exposed to 120VAC can be determined using Ohms Law as follows:

$$I=E/Z$$

$$I=120/1500$$

$$I=80mA$$

Where I =Body Current in Amps

E =Shock Exposure Voltage

Z =Body Impedance in Ohms

Once the level of current flow through the body has been established, the maximum withstand time without heart fibrillation can now be calculated using the fibrillation threshold formula as follows:

$$I^2t=0.027$$

$$t=0.027/I^2$$

$$t=0.027/(0.080)^2$$

$$t=4.2 \text{ seconds}$$

Where I =Body Current in Amps

t =Withstand Time in Seconds

This same process can be used to determine the withstand times at other circuit voltages.

Since the 150 lb individual cannot be exposed to an 80mA current longer than 4.2 seconds without initiating heart fibrillation, the maximum operating time of the circuit overcurrent device (fuse or circuit breaker) is 4.2 seconds. Figure C-23 illustrates a time/current curve of a typical thermal-magnetic 20 Amp circuit breaker. To operate this device in 4.2 seconds requires a current of 600% of the breaker rating. For a 20 Amp breaker, the minimum current required would be $6 \times 20\text{A}$ or 120 Amps.

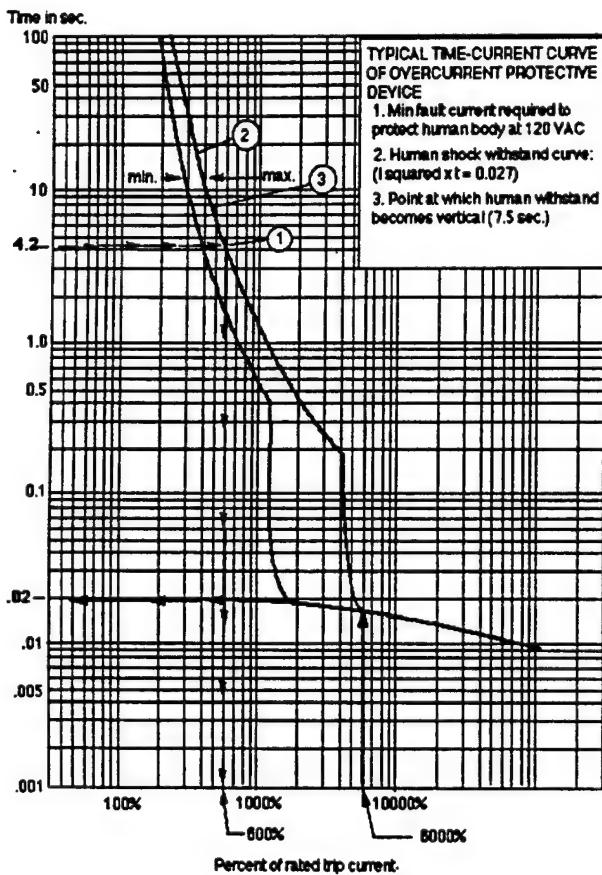


Figure C-23 Typical Time/Current Curve of a 20A Circuit Breaker

To achieve personnel protection under a worst case ground fault condition using the

above 20 Amp circuit breaker, the maximum impedance of the equipment grounding conductor can be calculated using Ohm's Law as follows:

$$Z=E/I$$

$$Z=120/120$$

$$Z=1.0 \text{ ohm}$$

Where Z =Equipment Ground Impedance in Ohms

E =Circuit Voltage (phase to ground) in Volts

I =Current in Amperes

In summary, the maximum impedance level of the Equipment Grounding Conductor is a function of the phase to ground voltage of the system and the particular overcurrent device used to protect the circuit.

Although no National Standard exists to define impedance values, experience has shown that properly installed and maintained Equipment Grounding Conductors will exhibit impedance levels of 0.25 ohms or less.

If the Equipment Ground in the sample circuit (Figure C-22) had an impedance of 0.1 ohms instead of 1.0 ohms, personnel protection would be enhanced as shown below:

Circuit Voltage

$$(E)=120\text{VAC}$$

Equipment Ground Impedance

$$(Z)=0.1 \text{ ohms}$$

The fault current can be determined using Ohm's Law.

$$I=E/Z$$

$$I=120/0.1$$

Thus $I=1200 \text{ Amps}$

For a 20 Ampere circuit breaker, 1200 Amps is 6000% of the breaker rating. Referring to Figure C-23, it can be seen that the trip time of the circuit breaker is now 0.02 seconds (20

milliseconds). The level of safety and protection of the operator has been greatly enhanced by reducing the impedance of the Equipment Grounding Conductor. From the above calculations, it can be concluded that the level of personnel safety and protection is a direct function of the impedance of the Equipment Grounding Conductor.

Note that The Earth Electrode System plays NO role whatsoever in the performance of the Equipment Grounding System in providing overcurrent protection and personnel safety. The Earth Electrode System could be completely disconnected and personnel safety will NOT be affected AS LONG AS THE LOW IMPEDANCE OF THE EQUIPMENT GROUNDING SYSTEM IS MAINTAINED.

Using the Earth Electrode System to accomplish the safety objectives of the Equipment Grounding System can be fatal! Figure C-24 illustrates how personnel protection is nonexistent when the equipment cabinet or frame is connected to the Earth Electrode System instead of the Equipment Grounding System.

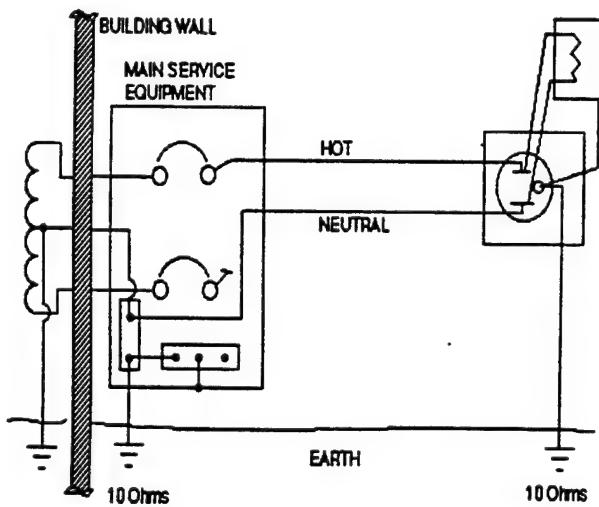


Figure C-24 Improper Connection of Equipment to Earth

In this example, if the Earth Ground connections were each 10 ohms, the fault current developed would be

$$I = E/Z$$

$$I = 120/20$$

$$I = 6 \text{ Amps}$$

A fault current of 6 Amps would not be sufficient to trip even a 15 Amp circuit breaker. The 80 mA of body current through the equipment operator will cause heart fibrillation and death! This method of grounding represents several serious violations of the basic safety requirements of the National Electrical Code including the following: 250-51 EFFECTIVE GROUNDING PATH

"The path to ground from circuits, equipments, and conductor enclosures shall:

- (1) be permanent and continuous;
- (2) have capacity to conduct safely any fault current likely to be imposed on it;
- (3) have sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit; and
- (4) **THE EARTH SHALL NOT BE USED AS THE SOLE EQUIPMENT GROUNDING CONDUCTOR."**

Also, section 250-54, COMMON GROUNDING ELECTRODE, of the NEC states that "Where an AC system is connected to a grounding electrode in or at a building as specified in Sections 250-23 and 250-24, THE SAME ELECTRODE SHALL BE USED TO GROUND CONDUCTOR ENCLOSURES AND EQUIPMENT IN OR ON THAT BUILDING. Two or more electrodes that are effectively bonded together shall be considered as a single electrode in this sense."

Section 250-91(b) TYPES OF EQUIPMENT GROUNDING CONDUCTORS states:

"The equipment grounding conductor RUN WITH OR ENCLOSING THE CIRCUIT CONDUCTORS shall be one or more or a combination of the following:

Section 250-91 (b), BUT THE EARTH SHALL NOT BE USED AS THE SOLE EQUIPMENT GROUNDING CONDUCTOR."

250-91(c) SUPPLEMENTARY GROUNDING "Supplementary grounding electrodes shall be permitted to augment the equipment grounding conductors specified in Section 250-91

All communications/electronics equipments in a Telecommunication facility [or commercial building] must be effectively grounded through the Equipment Grounding System to assure overcurrent protection and personnel safety. Bypassing the Equipment Grounding System in an attempt to reduce noise levels on equipments violates the basic safety requirements of equipment grounding contained in Article 250-51 and is forbidden.

Ground Fault Circuit Interrupters Ground Fault Circuit Interrupters are commercially available in 120VAC, 15 and 20 Amp configurations. They contain a torodial coil that senses unbalance of current between the phase and neutral conductors. When the current unbalance reaches 5mA (.005A.), the device will open and de-energize the circuit. Although they provide personnel protection against shock and electrocution, they shall not be used in Telecommunication installations since inadvertent tripping of these devices would interrupt power to the equipment and adversely affect the mission performance. Maintaining the equipment ground impedance levels within the requirements of

0.25 ohms will achieve the desired objectives of personnel protection. The use of Ground Fault Indicators on outlet strips to detect the presence of ground current is permitted and highly recommended. These devices will not cause interruption of power to the equipment.

Equipment Protection Equipment protection can be provided by two means: (a) effective grounding of circuits and equipments; or (b) the use of the Ground Fault Protection (GFP) on the overcurrent device.

Maintaining the equipment ground impedance levels within the requirements of 0.25 ohms will provide a high level of overcurrent protection under ground fault conditions resulting in fire and equipment protection.

It should be noted that the GFP on the overcurrent device DOES NOT provide personnel protection since the trip point is normally set at several hundred amps which is well above the shock withstand level of the human body. The intent and purpose of GFP is to protect equipment from arcing ground faults on 480 volt and 600 volt systems. Figure C-25 illustrates the installation of GFP on a main breaker.

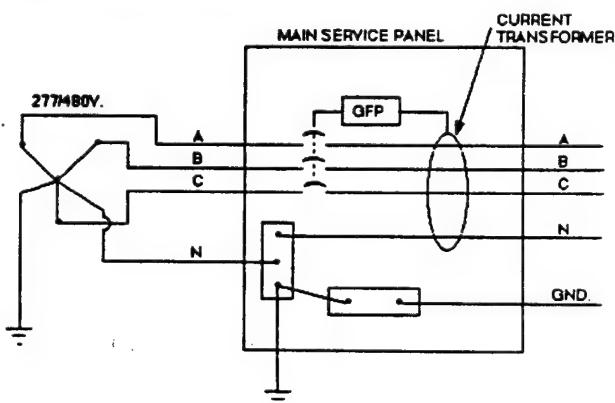


Figure C-25 Ground Fault Protection Installed on Main Breaker

Maximum Impedance Levels

For Telecommunication installations, THE MAXIMUM IMPEDANCE OF EQUIPMENT GROUNDING CONDUCTORS (GREEN WIRES) AND GROUNDED CONDUCTORS (NEUTRALS) SHALL NOT EXCEED 0.25 OHMS.

OPERATION: The supply conductors (3-phases, 1-neutral) are installed through a current transformer as shown. Under normal conditions, all outgoing currents will be cancelled by the return currents so the output of the current transformer is zero. When a ground fault occurs, the current flowing out the phase conductor and returning on the grounding conductor will create an unbalance that will be sensed by the current transformer. The GFP control circuit can be set to trip the main breaker at a pre-set level of ground fault current (usually 5-500A) and a pre-set time delay (usually 0-2.0 seconds).

NEUTRAL-GROUND BONDING

At the main service equipment, a main bonding jumper connects the equipment ground bus to the neutral bus. This connection, required by Article 250-23(a) of the National Electrical Code, extends the earth "zero voltage" reference point to the ground bus where all equipment grounding conductors (safety grounds) are terminated. The main bonding jumper is also required to provide a low impedance path for fault currents to return from the equipment grounding conductor to the service neutral.

Location

It is important to keep in mind that the connection of equipment grounds to neutral must only be made inside the main service panel. An exception to this is if a new electrical system is separately derived through a transformer. See page 111 for grounding of separately derived systems.

Improper connections of neutral and equipment grounding conductors is a major cause of malfunction and failure of communication and electronic equipments in Telecommunication installations.

The reason the only connection between neutral and equipment ground shall be made at the main service panel (or on the secondary side of a transformer) is to minimize the possibility of current flow on the equipment ground under normal operating conditions. Any current flowing on the equipment ground will create a potential above zero volts. The amount of voltage rise is a function of the load current and the impedance of the equipment grounding path.

Improper Neutral-Ground Bonding

If neutral and ground are connected at any point on the load side of the main service equipment, the neutral current will divide and return to the main service on both the neutral and equipment grounding conductor. This will cause a voltage above "0" to appear on all pieces of equipment located downstream from the second neutral-ground connection. This problem is illustrated in Figure C-26.

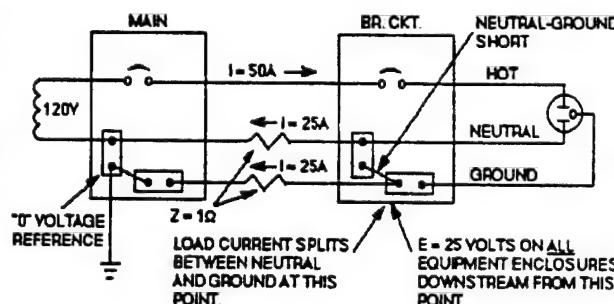


Figure C-26 Neutral-Ground "Short" Condition

In this example, a neutral-ground short has occurred in the branch circuit panelboard. If the impedance of the neutral and safety ground are each 1 ohm and the total neutral

current is 50 amps, this current will divide equally at the neutral-ground short with 25 amps flowing on both the neutral and safety ground from the branch circuit panel to the main panel. This will cause a potential of 25 volts above ground to appear on all equipment that is served from the branch circuit panelboard! This potential will not only create a serious shock hazard to personnel in contact with equipment enclosures, it will also create serious equipment operational problems and can easily result in mission failure.

TOPOLOGICAL BARRIER GROUND

Electronic systems must be grounded to prevent the buildup of static charges and to protect against the danger of personnel shock or equipment damage from ground faults. To prevent noise the optimum grounding method is the single point ground. However, this is almost impossible to achieve because of the multiplicity of coaxial cable shields used in modern equipment. When electronic systems are grounded via multiple paths, loops are formed in which noise currents are induced. To minimize the effects of noise currents, the power and signal grounding systems in Telecommunication installations require a "topological barrier ground".

Skin Effect

The topological barrier works because of the phenomenon that an electric field penetrates a conductor or enclosure only to a certain depth, called the skin depth. This depth is dependent on the frequency of the signal.

For example, in aluminum a 60 Hertz current will penetrate about 1 centimeter into the metal before beginning to be significantly attenuated. With a wall thickness of less than 1 centimeter, the 60 Hertz current passes through essentially unimpeded. A 10 megahertz signal (or noise current) in the

same metal will penetrate only about 0.025 centimeters. In other words, RF currents simply will not pass through the barrier.

Grounding systems inside a topological barrier to the inner surface of the barrier, and continuing the ground path from the outside surface of the barrier, does two things. It assures the safety of the equipment and personnel inside the barrier by providing a path which will return any DC, 50 or 60 Hertz, or other low frequency currents to the appropriate power source via the barrier. It also assures that any stray RF currents remain within the barrier. In addition, the barrier will attenuate any external RF currents on the power equipment grounding system from continuing through to the inner surface of the barrier. An equipment chassis, a metal equipment rack, a metallic screen, or even a metal building wall, is an effective barrier to RF currents while allowing 50 or 60 Hertz or DC currents to pass unimpeded. Thus any of these barriers can be used to contain and restrict noise currents while still providing a safe and effective ground fault path. Isolating the noise currents in this way prevents the noise generated by one system from affecting another system, which is the key to EMI/RFI control.

SIGNAL GROUNDING

Signal grounds shall be installed utilizing the "topological barrier" concept. An equipment case, chassis, or cabinet is a barrier containing currents which should not be coupled to other equipments. No signal ground conductor should freely penetrate the barrier. Signal cables which exit the equipment should be completely shielded. Signal ground conductors must not penetrate the barrier. Rather a signal ground connection must be made to the inside surface of the barrier and then continued from the outside surface of the barrier. Increased levels of

isolation can be achieved by establishing a "barrier within a barrier," and so on. A building can be the first level of isolation, a room the second level, a bay or cabinet the third level, and an equipment chassis the fourth, for example.

Only equipment inside a bay or cabinet should be connected to the internal bus bar; the external ground connection should be made only from the outside surface of the bay or cabinet. This principle applies to all enclosures, not just to the so-called "RFI cabinets," or other specially shielded enclosures. The principle applies to both the signal grounding conductors and the power system equipment grounding conductor (Safety Ground). It should be noted that, while discussing noise prevention, the purpose of grounding remains safety. Care must be exercised in designing the equipment grounding system that paths are not created for noise to be generated or to be propagated or conducted from one system to another.

Installation of the Barrier Power Units, described under "GROUNDING SEPARATELY DERIVED SYSTEMS" (later in this Appendix), in rooms where sensitive electronic equipment will be utilized provides a topological barrier that will reduce the effects of noise currents on the equipment grounding system. The key to preventing the ground currents of one system from interfering with other systems is containing them within a barrier formed by a chassis, equipment cabinet, conductive room or building wall or other shell. The two key points are: (1) coaxial cable shields maintain the barrier integrity beyond the equipment chassis or case, and (2) equipment grounding conductors (Safety Grounds) do not penetrate barriers crossing from one level to another.

One level of the topological barrier ground will be established at the Barrier Power Unit

supplying power to the panels in the room. A second level should be established where the branch circuit conductors enter the equipment bay or cabinet. A third level can be established at the equipment chassis within the cabinet.

Incorrect Single Point Grounding

The common practice of connecting equipment cabinets to a room ground bus by connecting a wire from the cabinet's internal bus bar, through the open bottom of the cabinet or through an opening in its top, to the room bus bar, is a direct violation of the topological barrier concept. This permits noise currents generated inside the cabinet to be transferred to the larger ground bus and thence to other cabinets and systems, and vice versa.

The individual equipments in the cabinets are connected to a ground bus inside the rack, which does not penetrate the cabinet, but connects to its inner surface. Connected to the inside of the cabinet, RF ground currents are kept on the inside surface of the cabinet. Only the outside surface of the cabinet is then connected to the larger system ground bus. Care must be taken to ensure that the National Electrical Code requirement for a low impedance ground path is observed. The low impedance path, of less than 0.25 ohms, is required to ensure that the overcurrent device will be tripped in case of power fault. The signal ground connections to the Signal Reference Grid are used to supplement the equipment grounding conductor but they can never be used in place of the equipment grounding conductor.

Existing Facilities

There are conflicting recommendations and requirements in the existing MIL-STDS as to exactly how RED and BLACK grounding systems should be designed and installed. A single point grounding scheme has been

recommended for LF equipment and a multi-point scheme has been recommended for HF equipment.

Although in theory these designs may seem ideal, in the practical real world installations, both types of equipment are present and are normally interconnected through multiple paths including data and communications cables. Attempting to isolate systems with a single point ground is not practical or economically feasible. MIL-HDBK-419A addresses this point in Section 1.5.2 as follows:

"LOWER FREQUENCY SIGNAL REFERENCE SUBSYSTEMS ARE NOT TO BE INSTALLED IN COMMUNICATIONS-ELECTRONICS FACILITIES."

Facility upgrades are covered in Section 2.2.5 as follows:

"WHEN BOTH HIGHER AND LOWER FREQUENCY REQUIREMENTS MUST BE MET, A HYBRID SYSTEM MAY BE REQUIRED BUT IN MOST CASES THE EQUIPOTENTIAL PLANE WILL SUFFICE FOR BOTH REQUIREMENTS."

RED/BLACK grounding systems in existing facilities are covered in Section 2.4.2 as follows:

"SINGLE POINT SIGNAL GROUND SYSTEMS (either RED or BLACK) WILL NOT BE INSTALLED IN NEW OR UPGRADED FACILITIES PROCESSING CLASSIFIED INFORMATION. ANY MAJOR BUILDING OR FACILITY REHABILITATION SHOULD INCLUDE UPGRADING THE SIGNAL REFERENCE SUBSYSTEM TO INCLUDE USE OF THE EQUIPOTENTIAL PLANE. ALL ADDITIONS TO BUILDINGS SHALL INCLUDE AN EQUIPOTENTIAL PLANE IN ACCORDANCE WITH MIL-STD-188-124A." [Note: this latter requirement was

left to the discretion of the engineer in charge of the construction in the revision of MIL-STD-188-124B.] Proper installation of signal reference grids as described in the following Section will create an effective signal grounding system.

SIGNAL REFERENCE SYSTEM

Introduction

The signal reference system establishes a voltage reference and controls noise currents in the facility, so that relative voltage levels are maintained and unacceptable noise voltages do not occur on signal paths or circuits. Within a piece of equipment, the signal ground may be a bus bar or conductor that serves as a reference plane for some or all of the signal circuits in the equipment. Between equipments, the signal ground will be a network consisting of a number of interconnected conductors.

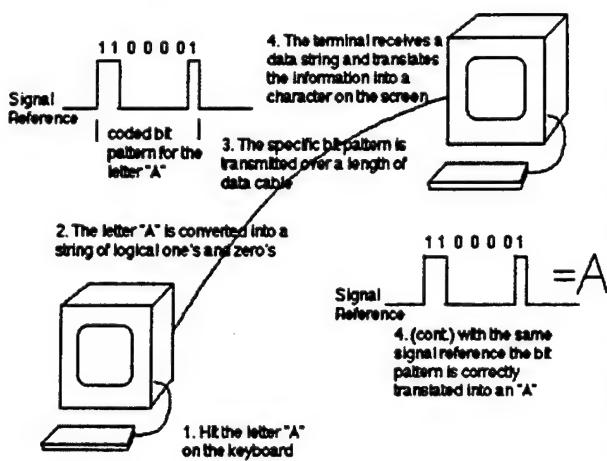
Whether serving a collection of circuits within an equipment or serving several equipments within a facility, the signal reference network will be a multiple-point, or hybrid ground, depending on the equipment design, the facility, and the frequencies involved. One of the most important advances in communications technology is the increased speed at which data is able to be transmitted, allowing faster transmissions over longer distances. As technology advances, the need to have these same communications devices installed and maintained properly becomes just as critical. The signal reference grid is one portion of reliable communications that is either applied improperly or neglected altogether. In either case, the results are intermittent or failed communications which become evident through dropped network links, garbled data at terminals, improper data being written to a disk or even system crashes.

These "commonplace" occurrences can be practically eliminated through the proper installation of signal reference systems throughout Telecommunication facilities.

Importance of Signal Reference

Data communications is essentially the transmission and reception of a series of logical ones and zeros. The transmitter generates a series of data bits and sends them via MIL 188C, RS 232, RS 422, RS 449 twisted pair or coaxial cable to a receiver. It is at this point that the receiver must translate the logical bits of information into usable information for processing.

Figure C-27 illustrates the flow path for the transmission of a single keyboard stroke to a terminal at the other end of an RS232 communications cable.



For any form of communication to be effective, both receiver and transmitter must have the same logical reference established. The best reference in buildings with the complexity of Telecommunication facilities is earth. This would, in effect, establish zero volts as the logical reference point of every piece of communications equipment within the building. Therefore any transmitter could

communicate with any receiver within the facility based on the assumption that all communications device share the same reference. It is when the reference of one device changes with respect to any other device that "glitches" in data communications occur. Figure C-28 illustrates the possible effects of dissimilar references.

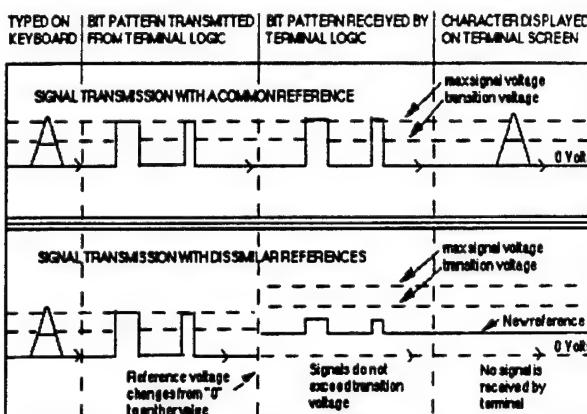


Figure C-28 Dissimilar Signal References

It may seem apparent, initially, that in order to ensure a common reference among communications devices, one need only guarantee the installation of a full-sized, insulated equipment grounding conductor to every chassis that contains one or more of these devices. But this would only ensure a low impedance path for 60 Hz currents. This is due primarily to the fact that at power line frequencies, the low impedance of the equipment grounding conductor allows sufficient current flow to allow overcurrent devices to respond. When the equipment grounding conductor is not carrying fault current, it has the secondary function of delivering the "zero-volt reference" to the reference point of communications devices - namely, the equipment chassis. Figure C-29 shows how this zero volts is "delivered" to equipment chassis.

As long as each piece of equipment has an equipment grounding conductor run with the

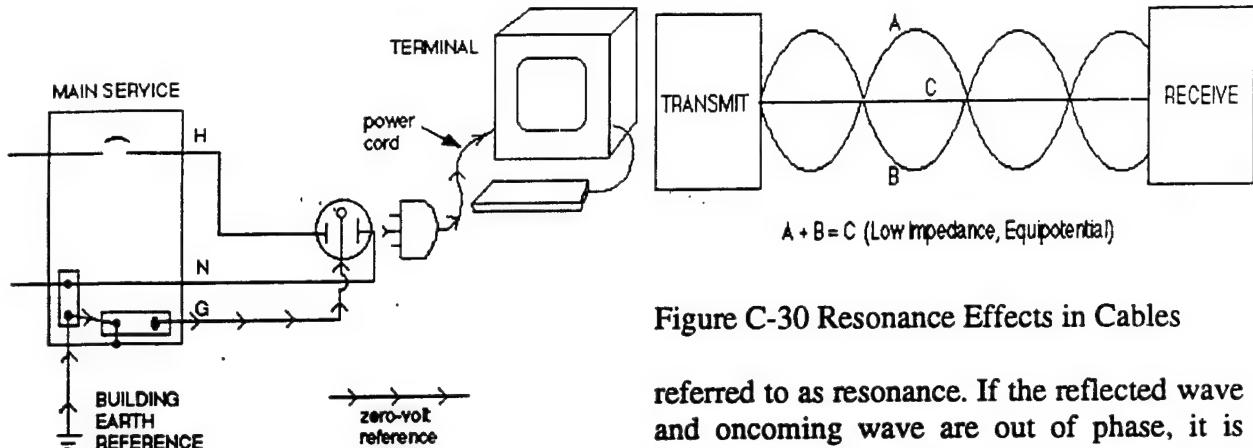


Figure C-29 Establishment of Zero-Volt Reference

phase conductors to its metal chassis, the same earth potential should be established on all enclosures. There are, however, other currents flowing through Telecommunication sites besides power line 60 Hz currents.

High Frequency Effects on Grounding Conductors

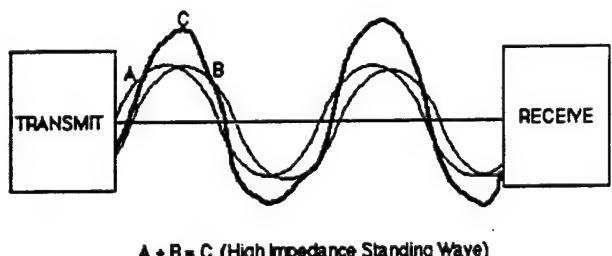
The large spectrum of communications and computer equipment in Telecommunication installations cover voltages and currents from 60 Hz to well into the Megahertz range. These same high frequency currents are the mechanism by which the equipment grounding conductor is prevented from delivering a "zero-volt reference" to every chassis.

When a signal of a fixed frequency is transmitted to a receiver, a reflection of that signal at the same frequency is generated when the signal reaches the receiver, similar to an ocean wave reflecting off a breakwater. (See Figure C-30.)

The speed of the reflected signal is insignificantly less than the original signal. If the original signal is reflected back and becomes in phase with the next transmitted signal, the signals become additive. This is

Figure C-30 Resonance Effects in Cables

referred to as resonance. If the reflected wave and oncoming wave are out of phase, it is referred to as being anti-resonant. When resonance occurs in a cable (Figure C-31), the impedance of that cable increases significantly as a result.



$A + B = C$ (Low Impedance, Equipotential)

Figure C-31 Anti-Resonance Effects

When that happens, the ability of a cable to deliver the required zero-volt reference to equipment enclosures becomes severely hampered. Figure C-32 illustrates this effect. It would seem apparent then, that in order to provide the same zero-volts to all enclosures within a building, special steps must be taken to prevent equipment ground paths from achieving a resonant state.

The easiest method to ensure anti-resonance in any length of cable is to prevent any transmitted wave from being large enough to achieve resonance when reflected. However, the first variable that must be determined is the wavelength for the particular transmission frequencies of concern. Once the wavelength of the frequency in a vacuum is determined, it

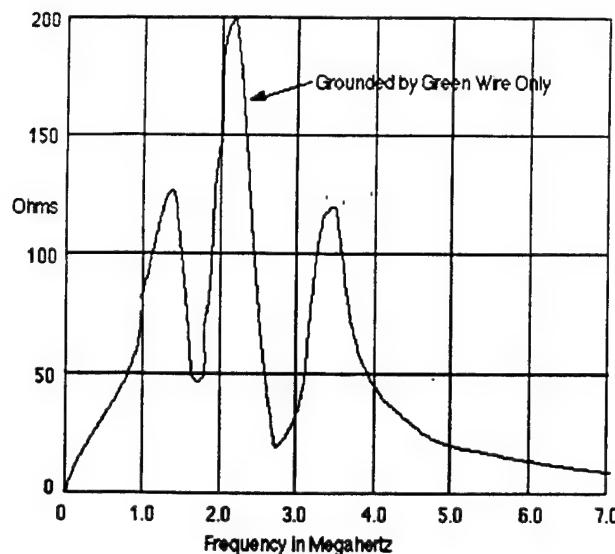


Figure C-32 Variation in Impedance of 22 Feet of #4AWG Copper - Grounded at One End

must be adjusted to account for the fact that the wave is being conducted in a grounded conductor. Knowing that the first resonance of any frequency occurs at one-quarter wavelength, a Table can then be constructed that shows the maximum free length of any grounding conductor that will be able to maintain an anti-resonant condition up to the given frequency. Further studies indicate that any conductor longer than 1/20th of wavelength is incapable of maintaining the same potential on one end of the conductor with respect to the other. Using this as a maximum length would ensure a low impedance in the ground path and a good logical reference for all equipment to operate effectively. For example, at 20 MHz, the vacuum wavelength is 49.1 ft, the conductor (copper) wavelength is 44.1 ft with a resultant 1/20th wavelength of just 2.20 ft. Similarly, the 1/20th wavelength for 30 MHz is 1.47 ft.

Signal Reference Grid Design Considerations

Signal reference grids provide a reference plane of constant potential over a very broad

band of frequencies. A grid provides multiple parallel conducting paths between its parts. If one path is a high impedance because of full or partial resonance, other paths of different lengths will be able to provide a lower impedance path.

Solid Sheet Grid A signal reference grid could be constructed of continuous sheet copper or aluminum, zinc-plated steel, or any number of pure or composite metals with good surface conductivity. However, this type of construction would not only be expensive but also difficult to install in a computer room where other services have already been or are about to be installed.

Copper Conductor Grid A grid of copper conductors on approximately 2-ft centers provides a satisfactory constant potential reference network over a very broad range of frequencies from dc to well above 30 MHz. Typically these have been formed of #4 AWG copper conductors, which have been electrically joined at their intersections, or by copper straps some 0.010 inches thick by 3-4 in wide, also joined at their intersections. These grids typically lie directly upon the subfloor under the computer room raised floor. Cables and conduits under the floor would normally lie below the raised floor but above the grid. Figure C-33 shows a grid consisting of discrete conductors.

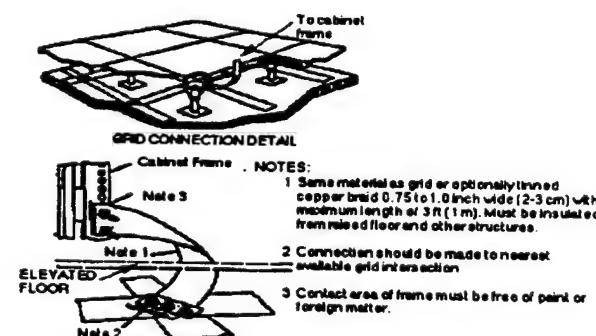


Figure C-33 Signal Reference Grid Using Copper Conductors

Raised Floor Stringer Grid The use of the raised floor supporting structure to serve as a signal reference grid has been proposed for some applications. This method is not to be used as a signal reference grid in Telecommunication facilities.

According to FIPS-94 (FIPS PUB 94,1983) experience shows it unnecessary that the lift-out floor panels make a low resistance contact with the supporting network of stringers. It is sufficient that the plastic or synthetic rubber cushions or molded edging upon which the panel rests be sufficiently conducting to drain static electricity from the panel to ground if any should accumulate. A resistance as high as 20,000 megohms under 20 percent relative humidity will satisfy this requirement.

The removable panels may be of metal or may have a plywood core; however, the lower surface of each panel must have metal cladding to satisfy flammability resistance requirements. When these metal or metal clad panels are placed into the raised floor to form a raised floor, their presence supplies damping to the electrical resonances which would otherwise occur at the radio frequency where the 2-ft-long members enter their lowest frequency resonance mode. Once a signal reference grid has been established in a computer room, the various equipment cabinets should be connected to that grid by flexible flat braided copper straps. The connection should be made from each cabinet, preferably at a point near its identified safety ground connection, to the nearest intersection of the reference grid. The strap should be no longer than 2 feet, and should have few bends and very little loop or sag to minimize the impedance at high frequency. Typical reduction in overall grounding impedance by use of a signal reference grid is illustrated in Figure C-34.

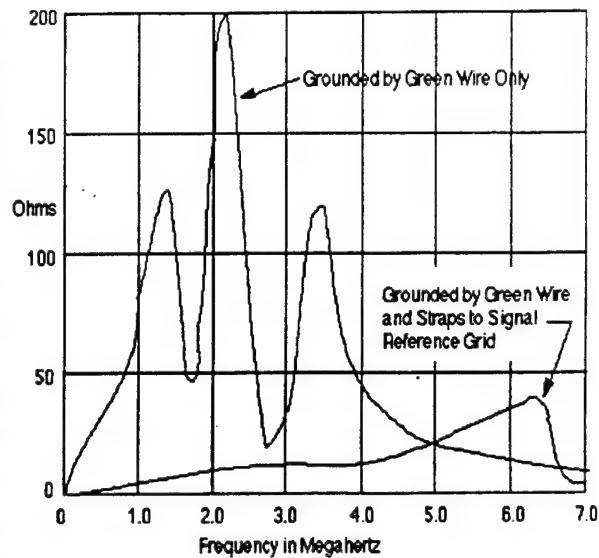


Figure C-34 Reduction of Impedance Using Signal Reference Grid

The effectiveness of the reference grid is further enhanced if it is connected solidly to the power system's central grounding point by a very short strap. This can be accomplished by installing one or more Barrier Power Units in the computer room, each being placed conveniently close to the loads which are to be served, particularly those electronic loads which transmit or receive the highest frequency data signals. Loads consisting primarily of small motors and no high performance digital circuitry (computer room air handlers, for example) need not be close nor have short leads. The Barrier Power Unit will have a secondary output winding that is grounded to the signal reference grid as well as to all other ground points required by electrical safety codes.

The AC voltage output to the equipments will thereby be isolated from outside sources of disturbance, and closely connected to the reference grid and to the loads by conductors too short to cause any resonance problems or to pick up other disturbances by induction. It is important, however, to adhere to the principle that the signal reference grid is not a

substitute for any safety ground prescribed by code.

Existing Installations

The raised floor in each communications space of Telecommunication facilities has the ability to be converted to a high quality signal reference system (Figure C-35).

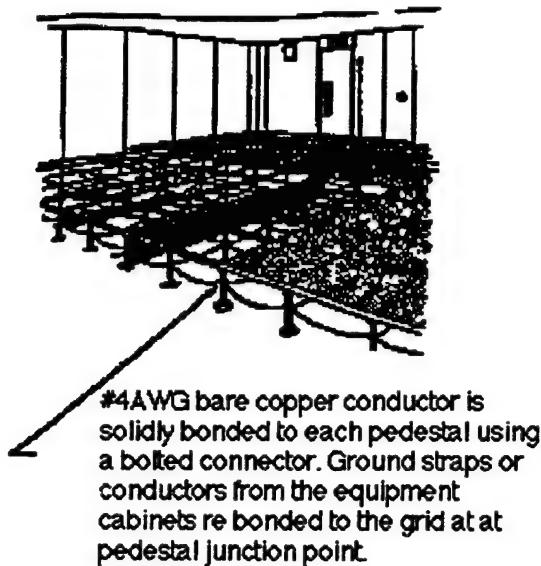


Figure C-35 Signal Reference Grid for Existing Installation

Since the pedestals of the raised floor systems are spaced on two foot centers, bonding a good quality conductor to each pedestal will provide less than quarter-wavelength spacing. The grid should be installed with good quality electromechanical connections at every junction. Bare copper conductor is solidly bonded to each pedestal using a bolted connector. Ground straps or conductors from the equipment cabinets are bonded to the grid at a pedestal junction point. This grid will then be bonded to the ground bus within the local power distribution panel. To ensure that all equipment within the space can benefit from the effects of a low-impedance signal reference grid, all equipment enclosures need to be bonded to this grid by a conductor less

than 2 feet in length. Additionally, to prevent the introduction of any undesirable frequencies into the space, all cable shields, metallic piping and conduit systems and structural steel should be bonded to the periphery of the grid. This grid will serve to ensure a low impedance ground reference over a very broad frequency spectrum and will enhance the development of a zero-volt reference for all communications equipment. The development of this grid provides an additional function with respect to the coupling of high frequency electrical noise from structural steel members into equipment enclosures. The signal reference grid becomes one plate in a large capacitor while the steel supporting elements of the floor and ceiling become the other plate. The large capacitance offered by this arrangement offers very low impedance to the coupling of high frequency noise from structural steel to the signal reference grid. This path is significantly better than the alternative path of structural steel to equipment enclosures.

Connections to Grid One important consideration is the elimination of corrosion on grid connections under the computer room raised floor. High humidity levels or the presence of moisture or vapors can cause corrosion of connections. Table C-7 lists various materials used in making electrical connections. When materials of different groups are joined in a corrosive atmosphere, the one in the lower number group will corrode.

In making electrical connections, metals in a single group will not cause corrosion. For metals in adjacent groups or with one group in between, corrosion can be eliminated by sealing the junction from the atmosphere.

Connection of two metals more than two groups apart can cause deterioration of the metal in the lower numbered group. These

Table C-7 Galvanic Effect of Metals

ANODIC or POSITIVE (corroding)	
Group 1	ALUMINUM ALUMINUM ALLOYS
Group 2	ZINC CADMIUM
Group 3	IRON STEEL
Group 4	SOFT SOLDER TIN LEAD
Group 5	NICKEL BRASS BRONZES COPPER
CATHODIC or NEGATIVE (protected)	
Group 6	SILVER SOLDER SILVER GOLD

connections should be protected with a metallic coating (or plating) of a group located between them. Additional protection will be realized by sealing the junction from the atmosphere.

Connection Resistance The maximum resistance of all connections at the grid junctions shall not exceed 100 micro ohms to achieve the desired noise rejection characteristics. The resistance measurements shall be conducted using a microohmmeter designed for the purpose.

SRG Installation Procedures

To properly prepare a raised floor space to become a high-quality signal reference subsystem, the following steps should be performed:

- Establish a 2 foot by 2 foot grid by bonding every pedestal of the raised floor grid to each adjacent pedestal using bare #4 AWG stranded copper cable.

- Attach the bare #4 copper cable using a good quality electrical-grade clamp which conforms to the geometric specifics of the pedestal to which it mounts (don't mount a round clamp onto a square pedestal). The pedestal clamp should also be capable of accepting two #4 AWG bare copper cables to allow for interconnectability between pedestals. See Figure C-36 for illustration of this installation.

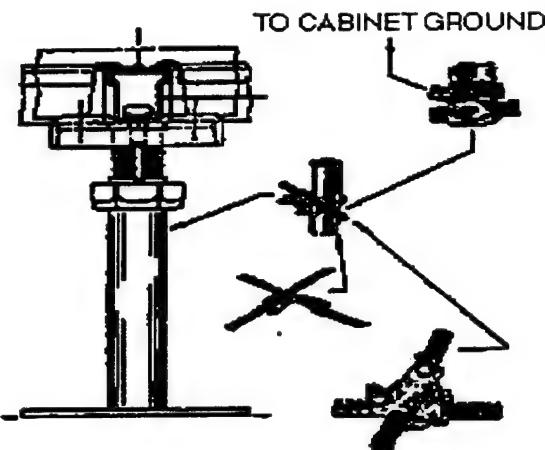


Figure C-36 Connections to #4AWG Copper Signal Reference Grid at Pedestals

- Connect the equipment ground bus of each power distribution panel and Barrier Power Unit in the space to the nearest intersecting point of the signal reference grid. This should be accomplished using flat copper braid to minimize the RF impedance. If copper wire is to be used, minimum size shall be #4/0 AWG. This connection to the signal reference grid will also provide a path for fault current in the event the raised floor attempts to rise to some potential above ground due to inadvertent contact with an energized conductor.

d. As exposed metallic objects penetrate the peripheral vertical boundary of the signal reference grid, the metal surface shall be bonded to the reference grid. This will include but not be limited to sprinkler systems, rigid metallic conduit for power or signal cables, freon and chilled water piping for process cooling systems, exposed structural steel elements including door frames, I-beams and re-bar. See Figure C-37 for illustration of these bonding connections. It is critical to ensure that the conductors bonding these members to the signal reference grid do not exhibit any free length greater than two feet. (Example: If the overall length of the conductor is 6 feet, it shall be bonded to structural steel every 2 feet to maintain anti-resonance during any possible condition.)

e. Every equipment enclosure shall be bonded to the nearest intersecting point of the signal reference grid. The bonding conductor shall terminate at one end, on the external surface of the equipment cabinet, and at the other end, in the nearest pedestal clamp. This bonding conductor shall ideally be a short, flat copper braid. If the length is kept to less than 2 feet, it can be constructed of the same #4 AWG bare copper that the grid is constructed. This method of bonding equipment cabinets maintains the concept of the topological barrier for noise reduction.

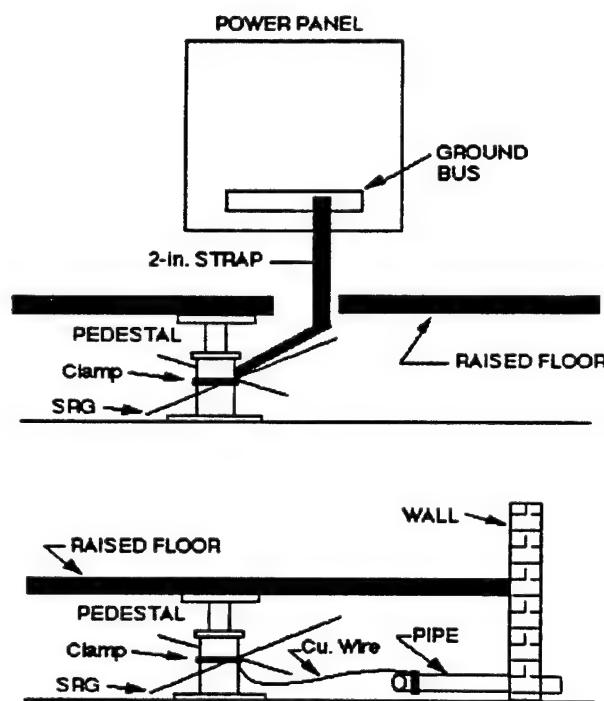


Figure C-37 Bonding Power Panels and Metal Structures to Grid

Verification of Grid Effectiveness

Verification of the effectiveness of the grid shall be performed once upon installation and periodically over the life of the system. This shall be accomplished by measuring the contact resistance of a large sample of intersection and connection points throughout the grid network. Using a low-resistance microohmmeter, the resistance across any junction point shall not exceed 100 micro-ohms. If the resistance is greater than this value, the segments of the grid connected through that junction will tend to allow resonance to occur and create potentials other than zero across their length. Locations of the test points and resistance measurements shall be documented on a test form. This will establish a bench mark upon which to evaluate the quality of the connections over the life of the installation. Following the initial measurements, periodic tests should be conducted and the results documented on an annual basis.

The Transient Trap

Data and power cables lying on the subfloor under a raised computer room floor will be electrostatically coupled to any reinforcing

steel in the concrete floor. If there is a large noise voltage appearing on the reinforcing steel with respect to the power system room grounding point, noise currents could be coupled directly into the shields of these cables and to a lesser extent into the conductors within those shields.

In addition to the installation of the Signal Reference Grid, use of a "Transient Trap" can also reduce any coupling of noise currents into power or communication cables.

A large sheet of copper is laid directly on the subfloor concrete surface and connected by a short connection to the Barrier Power Unit central grounding point. Minimum size of the plate should be 4 feet by 4 feet.

To be effective, the connection to the plate should be made using a flat copper braid or strap. Length of the connection should be kept as short as possible and must never exceed 3 feet. If copper conductor is used, minimum size shall be #4/0AWG. The plate will act as a bypass capacitor and alternate path for noise currents to flow rather than through the shields of data and communication cables. See Figure C-38 for illustration of the Transient Trap installation.

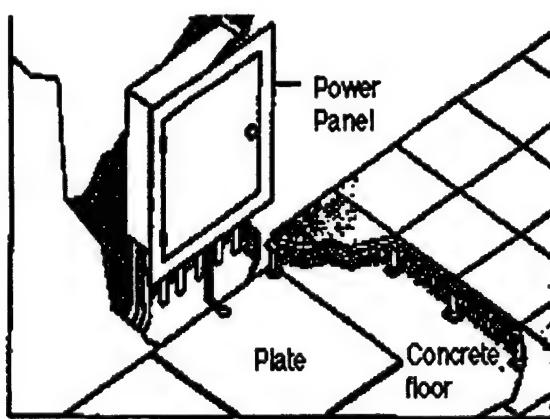


Figure C-38 Transient Trap Installation

In summary, effective and reliable communications are the backbone of the Telecommunication mission. Inadequate grounding and signal referencing techniques have led to an increased frequency of failed communications including "hung terminals" and system crashes. In order to ensure an increased level of performance of communications systems within Telecommunication facilities, every effort must be made to provide an effective form of signal referencing through the proper installation and maintenance of a signal reference subsystem in all spaces that contain communications equipment. Adherence to the requirements of the "topological barrier" concept described above is necessary when bonding equipment cabinets to the signal reference grid.

GROUNDING SEPARATELY DERIVED SYSTEMS

A separately derived system is defined by the National Electrical Code, Article 250-5(d) as follows: "A premise wiring system whose power is derived from generator, transformer, or converter windings and has no direct electrical connection, including a solidly grounded circuit conductor, to supply conductors originating in another system..." This means every time a transformer is installed in a building wiring system, a separately derived system is created.

Grounding of Transformers

The separately derived system is required to be grounded by Article 250-26 of the National Electrical Code including installation of a Bonding Jumper, Grounding Electrode Conductor and Grounding Electrode.

The Bonding Jumper can be located anywhere from the source (transformer secondary) to the first disconnecting means or

overcurrent device (first panel from the transformer secondary). It is normally made at the secondary of the transformer which means the neutral bus bar in the first panel must be isolated from the panel frame, otherwise a neutral-ground short condition will be created. For Telecommunication installations, all separately derived systems are to be operated as grounded systems as required by Article 250-5(b) of the NEC. This means neutral and ground must be bonded at the transformer secondary. Some manufacturers of computer isolation transformers supply the transformer without a neutral-ground bond. These transformers violate the requirements of the National Electrical Code!

The usual symptom is the measurement of abnormally high voltages (50-70 volts) between neutral and ground on the load (secondary) side of the transformer. Installation of the required neutral-ground bond at the transformer will eliminate this condition and reduce neutral-ground potentials to practically zero.

Transformer Connections

While transformers can be connected either wye or delta on primary and secondary, the recommended practice for Telecommunication sites is to connect transformers in a delta primary and wye secondary. This eliminates the need for a neutral conductor on the primary feeder.

In addition, the delta-wye configuration will prevent secondary harmonic currents from being passed on to the primary feeder. The harmonic currents will appear as a circulating current in the closed delta primary winding of the transformer.

Transformer Taps

Most transformers include taps on the primary winding that can be used to

compensate for voltages above and below normal. These taps are normally in 2 1/2% increments and, depending on the transformer, can compensate for +5%, -10% voltage variations.

Sizing of Transformers

An important consideration is the proper sizing of transformers for Telecommunication installations. Since the majority of loads to be served are communications/electronic equipments with switching power supplies, these are non-linear loads as described in Part II. The harmonic currents produced by these loads will become circulating currents in the closed delta primary winding of the transformer and not be passed on to the primary feeder. In selecting the size of any transformer, these harmonic currents must be considered in addition to the loads to be served. Recommended practice is to not load any transformer over 70 per cent of the nameplate rating. When estimating the connected load, be sure to include all possible future additions of equipments. Transformers operate at a very high efficiency (typically 95%-97%) over a broad range of load from approximately 25 per cent to 100 per cent of nameplate rating. Conservative judgment in sizing transformers will not adversely affect the operating efficiency and will be cost effective. If the future additional loads are unknown, the following example can be used to size the transformer:

- a. Determine the existing load to be served.
- b. Add 25 per cent for future growth.
- c. Divide the total load by 0.75 to determine the KVA size of the transformer.

EXISTING LOAD: 40KVA

FUTURE GROWTH:

$40\text{KVA} \times 0.25=10\text{KVA}$

TOTAL LOAD: 50KVA

TRANSFORMER SIZE:
50KVA/0.75=66.67KVA

In this example, the next largest size transformer would be a 75KVA. The 40KVA load on a 75KVA transformer would be approximately 53 per cent of nameplate rating which means the transformer would still be operating at a high level of efficiency.

Transformer Installations

Grounding In both single phase and three phase applications, the transformer creates a new power source since no direct electrical connection is made from the primary supply conductors to the secondary supply conductors. However, in all installations, the primary side equipment ground and secondary equipment ground must both be connected to the transformer case at the neutral-ground bonding point. Any deviation from this method of grounding will violate the basic safety requirements of the NEC and present some serious safety hazards to both personnel and equipment. The installation of plastic bushings in conduits supplying isolation transformers is forbidden by the safety requirements of the National Electrical Code, Article 250-75. All input and output conduits or raceways must be electrically continuous.

A Bonding Jumper is required on the secondary side of the transformer. This connection should be made between the secondary neutral terminal (X0) and the transformer ground terminal. This bonding jumper is required by Article 250-26(a) of the NEC. Without it, the output side neutral-ground potentials would be approximately 60 volts.

A Grounding Electrode Conductor is required by the NEC to connect the transformer ground terminal to a ground reference. This

connection should be made to the nearest effectively grounded building steel column, nearest effectively grounded metal water pipe or other suitable grounding electrodes as specified in Articles 250-81 and 250-83 of the NEC. This connection will normally be made to building steel.

Location To maximize the noise reduction characteristics, isolation transformers must be located as close to the loads to be served as possible. This will reduce the length of the circuit conductors from the transformer to the loads, minimizing conductor impedance and common mode noise. The preferred location is directly adjacent to the power distribution panel from which the branch circuits feed the equipments.

If more than one panel is used to supply loads in a room, then installation of the transformer in the room and distributing power to the room panels is recommended. Where multiple panels are located in different rooms, use two or more transformers rather than attempt to supply all panels from a single transformer.

Primary and Secondary Conductors When installing isolation transformers, it is always recommended to maintain maximum physical separation between primary and secondary supply conductors to prevent noise signals on the primary conductors from capacitively coupling into the secondary conductors and bypassing the noise rejection characteristics of the transformer.

Transformer Connections Figure C-39 illustrates a typical computer grade transformer installation. The incoming phase conductors are connected to the delta primary through terminals H1, H2, and H3. The incoming equipment ground is connected to the main ground terminal. Secondary phase

conductors are connected to terminals X1, X2, and X3 while the secondary neutral conductor is connected to the X0 terminal. The secondary equipment ground is connected to the output ground terminal where the neutral-ground bond is established.

Barrier Power Units Barrier Power Units (BPU's) are a special form of a separately derived system. These units incorporate a topological barrier grounding system with unique input and output distribution configurations to maximize rejection of high frequency ground currents and harmonic distortion on power systems supplying sensitive electronic equipments. The BPU's shall meet the requirements of topological barrier parameters covered on page 101. **ALL** transformers used in Telecommunication installations shall incorporate a topological barrier grounding system to reduce the effects of high frequency noise currents on the grounding system.

GROUNDING OF SHIELDED ENCLOSURES

Encapsulation of equipment to contain emanations involves surrounding the equipment with a stand alone RFI enclosure. Such encapsulation must include provision for the entrance of signal and power cables and provide adequate ventilation.

Total encapsulation may not be practical if operators must have ready access to controls and indicators. Where a quantity of equipment requires ready operator access to controls and indicators, such equipment may be placed in a screen room. Screen rooms are commercially available to provide attenuation and containment of emanations.

Careful attention must be given as to how the power and signal cables are grounded to

attenuate emanations without violating the basic safety requirements of the NEC and MIL-STDS. Unfortunately, several screen rooms have been installed that do not meet the safety requirements of the Codes. Conduits and raceways SHALL be continuous and cannot be interrupted with plastic bushings or sleeves. Equipment grounding conductors must be run in the same conduit or raceway as the supply conductors and not installed in separate conduits. By following the design criteria for the Topological Barrier, a grounding system can be designed for a screen room that will contain emanations as well as meet the safety requirements of the Codes.

Further attenuation of internal signals can be achieved by the installation of a Barrier Power Unit for the shielded enclosure. Applying the topological barrier principle where the power cables enter the enclosure will provide two levels of attenuation. See Figure C-39 for recommended installation of the power system for a shielded enclosure.

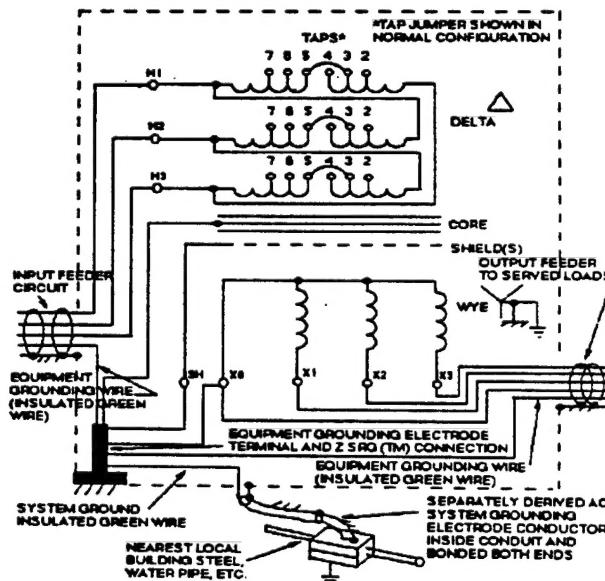


Figure C-39 Typical Computer-Grade Transformer Installation

Terminate the input and output conduits in junction boxes mounted to the wall of the shield room. Run the phase and neutral conductors through a grommet to the inside of the enclosure. Terminate the incoming equipment grounding conductor on a ground stud welded to junction box. Connect the internal equipment grounding conductor to the ground stud on the inside of the shield room.

GROUNDING DC SYSTEMS

DC power sources will normally be of the static, floating battery type and will be located in the vicinity but separated from the loads to be supplied. The basic station DC power source is usually +/-6 VDC. It consists of two or more rectifier-chargers, batteries, converter(s), and inverter(s) (if any). The rectifier-chargers float-charge the on-line battery bank(s) and also supply the DC load, converter, and/or inverter. Converters provide other DC voltages. Inverters supply power to the 115-VAC critical load. A typical 6-V battery bank consists of cells in a series string or, possibly, such strings connected in parallel, depending upon ampere-hour (Ah) requirements.

The NEC requires that the neutral conductors of all 3-wire DC sources supplying premises wiring be grounded. A 3-wire DC distribution system consists of a plus lead and a negative lead with a common return or neutral lead. The 3-wire DC distribution is not used in most modern facilities, because industry had adopted the 2-wire positive ground as standard, and most new equipment is designed and manufactured to this standard. The NEC also requires 2-wire DC systems to be grounded.

Commonly Occurring Problems

Experience has shown that inadequately designed or improperly installed recti-

fier-chargers, inverters, converters, and switching-type motor controls are major sources of internal electrical noise. Their effect can be minimized through proper placement, wiring, insulation, grounding, and filtering. DC power problems resulting from poor installation practices include DC currents in ground wire networks, due to multiple connections between the DC return wire and ground conductors.

DC currents flowing on the ground network will cause loss of the zero voltage reference for sensitive communication and computing equipment and can result in severe disruption of data communications.

Grounding

To minimize ground currents, it is critical that the DC system only be grounded at the source. This ground connection is normally made to the positive 6-V side and should be referenced directly to the Earth Electrode System of the facility.